13. Disruptive Inverse Infrastructures: Conclusions and Policy Recommendations

Tineke M. Egyedi

INTRODUCTION

Inverse infrastructures, that is, user-driven, self-organizing emergent infrastructures, disrupt the status quo. They do not blend in with institutions that were erected and matured in a historically different context, a context in which centrally governed and large-scale infrastructures dominated. As a result, a mismatch is becoming increasingly apparent. The gap between existing regulation and policies and the new inverse infrastructures is widening and questions arise such as: Must user-driven inverse infrastructures also comply with public network requirements specified for commercial parties? May citizen-owned information infrastructures (also) be tapped for national security? How should the tension between decentral energy generation and large scale electricity distribution be managed (e.g. issues of buy-back and universal service obligation)?

In this final chapter I re-address the aims of this book, that is, to explore the recent emergence of inverse infrastructures, characterize this new mode of infrastructure development, and probe its implications for infrastructure policy. This book's exploration follows from an interest in and recognition of the role citizens and home users play in technology development as well as the power of self-organization. It is inspired, first, by the movement that repositions users as a source of both active and unintentional innovation (e.g. Oudshoorn and Pinch 2008; Chesbrough 2003). Users matter, not only because they use technologies in unforeseen, innovative ways but also because they themselves develop new and innovative technologies, services, approaches, etc. A second, but equally inspiring source is the achievements of self-organizing communities, notably the open source communities (e.g. Raymond 1999), and interdisciplinary studies on self-organization (e.g. Complex Adaptive Systems, Gell-Mann 1994; Holland 1995; organizational theory, Brafman and Beckstrom 2007). In synthesizing the findings from the previous chapters, I will discuss issues that emerge from both streams of interest.

Vree's visionary identification of inverse infrastructures in the field of ICTs and waterways in his inaugural lecture (Appendix I) need not be restricted to this field. This book highlights that inverse infrastructure emergence is a cross-sectoral phenomenon deserving closer scrutiny. The authors of the previous chapters have taken up the task to apply critically and enrich the notions used in Vree (2003, Appendix I, this volume[1]) and the inverse framework developed by Egyedi, Vrancken and Ubacht (2007, Appendix II), each in their own way and own area of study. Some focused on prototypical inverse infrastructures (e.g. Wikipedia, Chapter 6; wind energy cooperatives, Chapter 7; Wireless Leiden, Chapter 8). They help identify common features across different sectors and settings (e.g. rural telecom in developing countries, Chapter 10), and highlight new inverse properties. Others use longitudinal case studies to position and challenge the rise of infrastructures historically and contextually (development of local radio and television distribution; Chapter 4) and help clarify their difference with the early emergence of LTSs (collection of waste paper, Chapter 5). Again other chapters explore the applicability of the concept for different purposes (syngas infrastructure design, Chapter 11; e-government projects, Chapter 12), highlighting hybrid inverse and designed realities and the interconnectedness of inverse and centralized infrastructures (water supply and sanitation, Chapter 9). Complementary theoretical frameworks are presented that highlight the conditions of inverse infrastructure emergence (Complex Adaptive Systems perspective, Chapter 2) and the institutional changes which this requires (institutional economics perspective, Chapter 3).

These new angles and insights are the basis for the further refinement of the inverse infrastructure framework and for re-positioning its scientific and policy significance in this conclusive chapter. First, key inverse properties will be reappraised in the light of the newly gained knowledge. The conceptual framework, including the core-set of properties, is adapted accordingly. Next, I synthesize theoretical and empirical insights about the conditions under which inverse infrastructures emerge, including a discussion of user incentives to initiate and contribute to them. This is a stepping stone for discussing insights from the case studies about the possibility to develop (centralized) policies that trigger and/or support inverse initiatives. The further synthesis of the key findings is structured along two intriguing questions that arose in the introductory chapter (Egyedi, Mehos and Vree): Are inverse infrastructures sustainable? And how distinct are they from other infrastructures? These seemingly straightforward questions allow us to explore the different aspects that determine the significance of inverse phenomena. The chapter closes by reflecting on the disruptive nature of inverse infrastructures and policies that bridge the gap between emerging inverse practices and their centralized institutional settings.

INVERSE PROPERTIES REVISITED

To summarize the key properties of inverse infrastructures as posited in Vree (Appendix 1) and developed in Egyedi et al. (Appendix II) and Egyedi and Mehos (Chapter 1), they are user-driven (initiation and/or participation), start out based on user investments (bottom-up), and develop in a self-organizing manner (decentrally governed coordination). While the essence of the concept and the elaborated framework remains upright, their application to a wide variety of cases in different cross-sectoral settings shows up a number of important nuances and enrichments.

User-Producers in Kind

The role of users in inverse infrastructures is crucial and, as the chapters illustrated, differentiated. In Vree's initial examples, end-users often with professional technical expertise drive inverse developments (e.g. ham radio amateurs and academics developing file transfer facilities) next to laypersons (e.g. car drivers as part of ad hoc networks). The previous chapters highlight ordinary citizens, home users and farmers as driving forces. But also village kiosks, small companies, and even large companies (Herder and Stikkelman) and government agencies (Van Veenstra and Janssen) can be rightfully viewed as users depending on the perspective taken. While under normal circumstances these users would ordinarily 'consume' or 'purchase' an infrastructure service from a provider, they collaborate with others to self-organize an infrastructure service. Instead of passive consumers, they are becoming co-producers of such services. The producer–consumer dichotomy is waning (Oudshoorn and Pinch 2008).

Technology may play a key role (e.g. wind energy, Kamp) in inverse developments, but it need not (e.g. household waste paper separation and collection, De Jong and Mulder). Where it does, sometimes the technological components are designed and implemented by end-users (e.g. Verhaegh and Van Oost); more often they are externally developed (e.g. Village Telcos and DakNet, Westerveld) and adapted to the local context. Similarly, the inspiration and impetus may come from within the user community (e.g. wikis, Nikolic and Davis) or from without (e.g. Rajendra Singh inspired reintroduction of traditional rainwater harvesting, Correljé and Schuetze). In sum, not only can different kinds of users drive inverse infrastructure development, they can do so in the role of inspirer, initiator, and/or contributor.

Inverse and Large

Thea Weijers points out in Chapter 4 that whether initial infrastructures are more LTS-like and centralized or more inverse and decentralized says little about the scale they may achieve and their final governance form. She illustrates this with the development of – the initially sizeable scale of – wired radio versus – the initially small scale of – wireless radio in the Netherlands in the 1920s. Scale alone is not a defining characteristic of inverse infrastructures, as also the classic example of Internet (Vree in Appendix I) and Wikipedia (Nikolic and Davis) confirm, both having become international and large-scale self-organizing efforts.

Upscaling a local, small-scale infrastructure often poses a technical and/or socio-institutional challenge. In the case of Wireless Leiden the – foremost technical – difficulties were successfully overcome (Verhaegh and Van Oost). However, the effort to upscale a successful pilot for household-centered sanitation services introducing urine-separating dry toilets in Kunming, Southwest China, failed – here foremost for socio-cultural reasons (Correljé and Schuetze).

Changing Nature of Inverse Infrastructure?

Egyedi et al. argue in Chapter 1 that whereas the characteristics of inverse infrastructures partly resemble those of early LTS-like infrastructures, there are crucial differences (see also Table IIA.2, Appendix II), the most essential one being the historical setting in which they emerge, i.e. within an LTS-dominated market and an LTS-oriented institutional context (policies, regulation, market arrangements etc.). Weijers adds an extra dimension to this discussion. She shows that initially inverse infrastructures (aerial and community antennas) may end up as LTSs (cable network), and warns us against the fallacy of retrospectively reinterpreting what at the time seemed like an early inverse development as actually having been an early LTS.

Weijers' longitudinal study, as the one by De Jong and Mulder, well-illustrate that also inverse infrastructures are dynamic and evolve, a process which researchers and policy makers must remain aware of. It raises questions such as whether inverse infrastructures change nature when they change scale. One might expect that increasing scale makes them prone to more top-down, hierarchic and centralized forms of governance, the underlying assumption being that efficiency requirements (low transaction costs) and economies-of-scale benefits favor centralized ownership and control.

For example, Brooks' Law predicts that the complexity and communication costs of a project rise with the square of people involved (Raymond 1999, p. 34). However, in the field of open source software this need not be the case. 'Until the Linux development, everyone believed that any software as complex as an operating system had to be developed in a carefully coordinated way by a relatively small, tightly-knit group of people. This model is typical of both commercial software and the great freeware cathedrals' (*The Cathedral and* *the Bazaar*, Raymond 1999, p. 16). But to Raymond's own surprise, Linus Torvald's approach of involving other users and being 'open to the point of promiscuity' turned out to be highly effective (p. 21).

The previous chapters also do not confirm Brooks' Law. If at all, the examples of Internet and the knowledge infrastructure Wikipedia would seem to deny it.

Inverse in Degrees

A number of important qualifications are made in the previous chapters about the original inverse framework (Table IIA.2, Appendix II; revised in Table 13.1). Among other things, to increase its value as an analytic framework, the properties identified to distinguish between inverse and design approaches to infrastructure development should be interpreted as extremes on a scale rather than as dichotomous categories. For example, a knowledge infrastructure such as Wikipedia typically has a decentralized mode of governance. However, this does not exclude more centralized editorial processes (e.g. Wiki Projects, Nikolic and Davis). The same applies to other properties. Likewise, in prototypical inverse infrastructure such as bit torrent content moderators (i.e. gatekeepers) are used to increase the quality of the content offered (Appendix II). (Similarly, open source communities have informal leaders.) That is, while for purpose of contrast and to help clarify inverse issues the two columns of design- and inverse-oriented characteristics are maintained in Table 13.1, they should be read as (relative) points on a scale. Indeed, the inverse end of the scale cannot always be narrowly defined; in practice also features common to LTSs can be part (e.g. involvement of commercial parties in FON; Appendix II). The chosen vantage point determines, for example, whether a local government-initiated project is identified as bottom-up or top-down (Van Veenstra and Janssen), or whether a local kiosk owner with central facilities (e.g. DakNet project; Westerveld) is viewed as part of a centralized or decentralized infrastructure. As a result, for example, government agencies can be (user-) drivers of inverse developments.

Approaching inverse characteristics as points on a scale rather than as one of two dichotomous categories also helps to avoid unfruitful discussions about whether or not an infrastructure should be called inverse. For example, Herder and Stikkelman use a hybrid mix of typical design-oriented (large-scale, government interest, R&D driven innovation) and inverse properties (self-organizing, bottom-up investments) to design a process supporting the development of a large scale syngas infrastructure. The syngas and the e-government (Van Veenstra and Janssen) cases indicate that also non-typical infrastructures may benefit from inverse approaches.

Table 13.1: Inverse features revisited

Characteristic	Design Approach	Inverse Approach
Driven by	Providers (government, large companies)	Users (citizens, companies*, government agencies*, etc.)
Investments (technology, effort)	Providers (top-down)	Users (bottom-up, local)
Ownership infrastructure	Defined (providers)	Can be undefined or defined (incl. user, community and mixed ownership)
Governance	Centralized	Decentralized
Scale	Large	Small, may end up as large*
Degree of homogeneity	Homogeneous	Heterogeneous, linked
Technology innovation	Classic, R&D-driven, by professionals	User innovation, innovation by experts
Coordination infrastructure development	Hierarchical (top-down), formal institutions*	Self-organization (bottom-up), more informal institutions*
Design focus on* (where relevant)	Content (blueprint of infrastructure)	Process (creating conditions for inverse development)
Outcome infrastructure development	Predefined	Less predictable, changing
Participants	Employed	Volunteers, self-employed or employed
Economy*	Market-based	Reciprocity-* & gift-based*, non-financial self-interest, market-based

Note: *New entries and additions. The columns 'design' and 'inverse' approach are to be read as relative on a scaled characteristic.

Source: Revised Table IIA.2, Appendix II.

New Inverse Properties: Expansions to the Framework

The inverse framework has been adapted accordingly. Table 13.1 now includes such non-typical inverse users as (decentral) government agencies and large companies. As a new entry it incorporates the distinction between a focus on content design, which is uncharacteristic for inverse infrastructures, and process design, the applicability of which has been explored for very large scale systems and is about creating favorable conditions for inverse infrastructure emergence (Herder and Stikkelman). The question how to create favorable conditions for inverse infrastructure emergence runs through several chapters, and is addressed below.

Furthermore, Table 13.1 presently reflects Künneke's observation that more informal institutional coordination is typical for self-organization in inverse infrastructures. Vice versa, formal coordinative arrangements are more typical for more centralized forms of infrastructure governance.

Finally, a new addition to the framework is 'economy' discussed by Verhaegh and Van Oost (see Table 13.1). It refers to the drivers underlying infrastructure organization and is based on their analysis of Wireless Leiden. They observe that infrastructure users, both technical experts and laypersons, contribute in essential ways to infrastructure development and maintenance based on mix of altruism, reciprocity and (non-financial) self-interest. The 'gift-based' economy noted by Verhaegh and Van Oost is also evident in citizen-driven collection of waste paper (De Jong and Mulder), Wikipedia contributions (Nikolic and Davis), and in initiatives to develop rural telecommunication (Westerveld) and re-introduce collective traditional rainwater harvesting (Correljé and Schuetze).

CONDITIONS FOR INVERSE EMERGENCE

Under what conditions do inverse infrastructures emerge? Jan van den Berg (Chapter 2) uses a Complex Adaptive Systems (CAS) perspective to analyze the circumstances and mechanisms under which spontaneous self-organization in inverse infrastructures may occur. His framework identifies five key elements: (1) the presence of actors or agents with a certain autonomy, (2) the means to communicate among them, (3) a drive to do so, (4) a state of delicate balance at the edge of order and chaos, which leads to complex behavior (here: self-organization), and which at the same time (5) makes such behavior susceptible to adaptation as a result of changing contexts and internal interactions. The system's state at the edge of order and chaos is one of high productivity, maximum variety and creativity (Van den Berg).

Using elements of his framework to structure our findings, I discussed the 'semi-autonomous actors' or users above. The synthesis below focuses on the role of communication in, and the drives users have for, self-organization. Following, using Künneke's approach, the institutional circumstances are discussed that may help stabilize the 'state of delicate balance at the edge of order and chaos', as Van den Berg puts it.

Communication: Low Thresholds

Inverse infrastructures are '(…) formed by means of many small private investments, investments which in many cases were going to be made for other purposes anyway' (Vree, Appendix I, p. 278). An inverse infrastructure is more likely to emerge if the extra cost of voluntary collaboration is low and the benefits high. It must be easy to initiate, coordinate and contribute. Inverse self-organization requires communicative interaction and feedback loops about local and non-local information (Van den Berg). The availability of easily accessible, user-friendly communication tools to support self-organization (e.g. infrastructure support software, Nikolic and Davis; Raymond 1999, p. 9), perhaps explains why many highly typical inverse infrastructures originate in the field of ICT (e.g. Internet, wiki software, Wi-Fi technology). The presence of Internet and the low cost of setting up and participating in Internet-based networks make it uniquely conductive for inverse citizen-driven initiatives in many countries (Nikolic and Davis). In this respect Van den Berg's framework also sheds light on the role of social media in political self-organization (e.g. the 'Arab Spring').

The ease of communicating between inverse participants also depends on the quality of personal relationships (notably trust) and the degree of interoperability between infrastructure components (notably standards). These reduce initial investments, financially as well as in time and effort, and are therefore essential to acquire critical mass and realize network effects.

Trust and cognitive distance

A necessary element of self-organization is the 'willingness and readiness of individuals to act and react' (Van den Berg). This requires the emergence of trust.[2] Trust is a recurrent catalyzing factor in many chapters. 'Assuming good faith' has been crucial for the growth of Wikipedia, despite making it more vulnerable to sabotage (Nikolic and Davis). Kamp speaks of the need for 'proximity' between parties in developing an inverse windmill sector by which she means geographical proximity, trust, a shared paradigm and a common language. These are needed to ease (interactive) learning from pilots. Herder and Stikkelman refer to the need for trust and the protection of core values in 'designing' inverse processes. In all examples the small cognitive distance between participants, including a common focus, eases coordination in self-organization (input and process coordination, Appendix II). For example, feeling a sense of community triggers reciprocal behavior (i.e. belonging, identification; Verhaegh and Van Oost; Weijers; De Jong and Mulder). If these conditions are present the likelihood of citizens assuming responsibility for and taking ownership of the shared infrastructure increases (e.g. Chapters 8, 4 and 5).

Standards

By providing a common basis, standards may ease inverse infrastructure developments in different ways. As part of the infrastructure backbone, standards guarantee interoperability and interconnection. The open, easily implementable Internet standards illustrate this. For inverse ICT developments sharing the same platform is a key prerequisite. Whether pre-specified elsewhere or developed by the contributing participants, standards enable low cost additions. (Reusable) standardized parts and modularity reduce infrastructure complexity and facilitate maintenance work (Van Veenstra and Janssen; Verhaegh and Van Oost; Westerveld).

Moreover, economically, lack of a standard may keep users from investing in inverse technologies. Standards help reduce market uncertainty (Correljé and Schuetze). In addition, open standards-based markets are more likely to deliver competitively priced inverse technologies (Westerveld). How products are priced determines whether or not users will invest both in developed as well as developing countries (e.g., Vree; Westerveld; Weijers; Kamp).

Incentives

Technically skilled volunteers are often vital for the emergence of inverse infrastructures (e.g., radio amateurs, Weijers; Wi-Fi users, Verhaegh and Van Oost; small manufacturers, farmers and agricultural cooperatives, Kamp). What drives them to initiate and contribute? The cases illustrate that to take off a new inverse infrastructure must (also) meet individual user needs or interests. Emergent processes start with an attempt to optimize a situation locally and only later lead to cumulative complexity (Appendix II). An inverse infrastructure must provide significant gains for participating individuals – and, where relevant, for the central authorities that support user-driven initiatives. These gains may concern:

- Extra infrastructure functionality. For example, better quality of broadcasted TV signals or the reception of additional foreign TV channels (community TV antennas), more bandwidth (Fiber-To-The-Home), or means to address seasonal water scarcity and use of fresh water resources (decentral water supply);
- Financial benefits. For example, access to low cost/free/more geographically dispersed infrastructure services (rural telecommunications; wind energy, Internet in city-wide Wi-Fi and FON; knowledge via wikis), or saving connection costs (rainwater harvesting);
- Increased independence from central suppliers (e.g. dissatisfaction with the quality of water supply and RTV services), and more personal control (e.g. on broadcasted content with community TV antennas; Fiber-To-The-Home; and intellectual autonomy in wikis);
- Professional interests such as curiosity and feeling technically challenged (wireless radio; city-wide Wi-Fi), seizing the opportunity to

increase one's reputation as an expert (P2P networks, city-wide Wi-Fi; wiki), increasing efficiency in multidisciplinary collaborations (wiki), or advancing the collective interest of running an infrastructure (city-wide Wi-Fi).

The fruits of contributing should be available in the short term. For example, joining the Unix-to-Unix Copy Program (UUCP) network facilitated from the start long distance email and discussions. With only a couple of days delay, it considerably improved scientific communication and collaboration.

Nikolic and Davis observe for wikis that the more one contributes, the more others will contribute too. It is a self-propelling process, which like the bandwagon mechanism and network externalities (Appendix II) reinforce user involvement. It increases the collective value of wikis and leads to positive network effects (Nikolic and Davis).

More community-related and collaborative incentives are:

- The fun of sharing and the sense of belonging to a community (e.g. wikis, community TV antennas);
- Rewarding feelings of good citizenship (e.g. in contributing to the post-war reconstruction and addressing the scarcity of raw material in citizen-driven collection of waste paper); and
- Feelings of reciprocity (home users in city-wide Wi-Fi; contributors to Wikipedia).

The motives of other types of users to participate are, for example, the prospect of expanding business for local entrepreneurs (rural telecommunications, FON); higher profits for large companies (syngas infrastructure); more control of expensive overcapacity for water companies (e.g. against overflowing sewers); and to solve local e-government needs for decentral government agencies.

The above examples show that the user needs and interests that underlie collaborative user-driven and often voluntary infrastructure development can be user-internal or external ones, that is, users may be intrinsically or extrinsically motivated. While external motivations are oriented towards meeting external goals (e.g. the promise of new functionalities and extra earnings) and are in that sense self-explanatory, intrinsic motivations are crucial in processes of self-organization. They entail initiating an activity because it is satisfying and rewarding in itself. In their seminal studies on self-determination, Deci and Ryan (2002) identify three essential intrinsic needs that underlie many of the user incentives noted in the previous chapters:

1. Competence, i.e., being effective in dealing with one's environment (e.g. seeking out technical challenges, deciding one's own broadcasted content):

2. Autonomy, i.e., being the causal agent of one's own life (e.g. develop means to address water scarcity, personally controlled exposure to media content); and
3. Relatedness, i.e., being connected to, interacting with and experiencing caring for others (e.g. cognitive proximity, fun of sharing, sense of belonging to a community, reciprocity).[3]

Their experimental findings indicate that these innate intrinsic needs that may drive inverse developments can be endangered (Deci 1971). External rewards provided to steer intrinsically motivated behavior may undermine the person's feeling of autonomy, an issue that I will return to in the policy section.

Note that the voluntary commitment of actors to cooperate in inverse infrastructures and their high degree of self-determination in many ways sets this cooperative context apart from many other settings (e.g. organizations). To understand better in which sense the inverse cooperative setting may differ, I turn to Axelrod (1984). He asks himself 'under what conditions will cooperation emerge in a world of egoists without central authority?' (p. 3) He uses the prisoner's dilemma, a game theoretical model, to formalize and explore cooperative behavior (Axelrod 1984). The game is designed such that while one can get the most points with 'egoistic' behavior per round, when several rounds are played, for both players mutual cooperation yields the best benefits. In such situations, where actor outcomes are set and interdependent, 'gift-giving is likely to be part of an exchange process' and 'altruism is a good name to give to the phenomenon of one person's utility being positively affected by another person's welfare' (p. 135). Maier (1999, p. 274) speaks of the joint utility approach, i.e., 'a situation in which each participant's well-being is partly dependent on the well-being of the other participants'. In such situations, altruism and trust are not even necessary for cooperation to take place; the notion of reciprocity suffices to explain its emergence (Axelrod 1984, p. 174).

Although the intrinsic needs of Deci and Ryan's self-determination theory seem to capture better the voluntary nature of inverse contributions, expectations of reciprocity and gained reputation, which are externally motivated, also play a key role for people contributing to inverse infrastructures (e.g., Verhaegh and Van Oost; Nikolic and Davis). Raymond's view on what drives Linux hackers to develop software voluntarily is that rather than maximizing classical economic utility they are maximizing their own ego satisfaction and reputation among other hackers (1999, p. 53).

Further research is needed to determine whether over time inverse collaboration increasingly takes on prisoner's dilemma characteristics. I surmise that during inverse developments functional and outcome interdependencies between volunteers grow, and will sometimes become institutionalized. Over time initial ‘gifts’ from volunteers are more likely to be taken-for-granted, and volunteers may feel less autonomous. That is, the set of intrinsic and extrinsic needs that drive volunteers is likely to change over time or lead to withdrawal – a dynamic similar to what happens in regular, formal organizations. Additionally, given the possibly heightening expectations of end-users about service delivery, the nature of the inverse infrastructure may change. It may professionalize and/or commercialize, thereby bringing to the fore the external motives that are dominant in the prisoner’s dilemma game.

New Inverse Institutional Requirements

Künneke uses theories from institutional economics to analyze the institutional circumstances that may help stabilize the ‘state of delicate balance’ of inverse infrastructures (Chapter 3). He argues that institutional non-alignment, as currently the case with most inverse infrastructures, usually leads to poor performance, friction, instability, change or even the discontinuance of infrastructures. To arrive at a more stable equilibrium between inverse technological practices, institutions and policy configurations a setting is needed that matches the ‘institutional logic’ intrinsic to inverse infrastructures. The conceptual framework he uses to explore systematically the features of the inverse ‘institutional logic’, for example, highlights that informal institutions and arrangements are more significant in the culture of cooperation of inverse infrastructures than is common in other infrastructures. Nevertheless, formal and explicit modes of coordination are also needed, new ‘rules of the game’ that encourage a more diversified infrastructure market, and that can handle small-scale infrastructures, unclear forms of infrastructure ownership, and infrastructure developments with unpredictable outcomes. At present many formal policies and institutional arrangements are missing.

In the way they shape the institutional setting for inverse infrastructures, governments must overcome the seeming tension between, on the one hand, the strong national interests in and public values attached to infrastructure services and, on the other hand, the means to safeguard them. To inspire policy makers, Künneke points to what Elinor Ostrom calls ‘polycentrism’ as a possible suitable form of decentral control. While government authorities may initially feel uncomfortable about using decentral control for essential infrastructures (e.g. drinking water or energy supply), polycentrism allows for multiple and diverse forms of governance – an institutional diversity that responds better to the socio-cultural differences between often locally-rooted inverse infrastructures.

EXPLORING CENTRALIZED POLICIES: INVERSE CONDITIONS

Understanding the incentives and conditions for inverse infrastructure emergence is a prerequisite for those who regard self-organization positively and want to instigate inverse processes – for example, because of the innovation it may trigger (Van Veenstra and Janssen), its higher effectiveness (local appropriateness, Westerveld) and acceptance (Herder and Stikkelman), or the user involvement it entails (e.g. societal embeddedness, De Jong and Mulder). While organizing 'spontaneous' processes may appear a contradiction in terms, it is part of a wider trend in system design (Herder and Stikkelman). A shift is taking place away from blueprint approaches towards 'creating the right conditions and constraints for the system to move into the desired direction relatively autonomously', Herder and Stikkelman note. Several of the previous chapters shed light on how central government may shape the circumstances that enable sustainable self-organization. Before summarizing their findings, a general issue must be noted.

A defining characteristic of inverse infrastructures is that they arise in a period and context in which large scale infrastructures dominate the landscape and a high level of institutionalization has already occurred (Egyedi et al.). Whether they are fully user-driven and self-organize, or instigated and supported by policy, the cause of their 'spontaneous' emergence is usually to be found in institutional (dis)incentives (e.g. Correljé and Schuetze). Because inverse infrastructures may strongly vary, comparing and generalizing about (dis)incentive structures can be risky. For example, whereas price-based incentives for citizen-driven infrastructure development may be effective in some areas (e.g. solar energy), price reductions may have little impact on volunteers motivated by technical challenges.

Kamp (Chapter 7), who compares Dutch and Danish policies for developing a wind energy industry, concludes that for inverse initiatives to develop and survive a consistent and long-term oriented set of policies is needed. This set should include:

- Incentives to form networks and distribute knowledge among participants (e.g., windmill producers, future owner-users, R&D centers, policy makers). These should aim to catalyze interactive learning (applicable knowledge) and proximity (including trust and shared knowledge);
- Carefully targeted R&D subsidies for small companies to initiate wind turbine manufacturing, and to support the knowledge demand of producers (i.e., not knowledge supply from R&D centers);
- Investment subsidies to create a demand and stimulate a home market; and
- Government funding to support upscaling small-scale inverse initiatives, the formalization of incremental knowledge, and industry export.

The longitudinal case study by De Jong and Mulder (Chapter 5) is unusual in that it describes the conditions that have enabled the nested, citizen-driven waste paper collection infrastructure to emerge and survive from the late 1940s onward. Over the years the Dutch government has used different policies to successively encourage, protect, conserve, integrate and, as one could argue, assimilate this inverse infrastructure. These policies ranged from national campaigns (e.g. tying into values of community engagement and environmental concerns), allowing municipal freedom in how to organize waste paper collection locally (institutional localization), price intervention (guaranteed minimum price for collected waste paper), installing a national platform for the sector, special arrangements for volunteers to use equipment and vehicles from the municipal paper collection department, and safety training to allow volunteer participation in the municipal waste collection system. The chapter highlights that citizen motives change (from addressing scarce resources to increasing environmental consciousness), as well as the societal context (e.g., end of the war), markets, and the technologies used by the industry. This requires a dynamic approach to policy.

Van Veenstra and Janssen (Chapter 12) explore patterns in developing building blocks for e-government services nationally. Based on the merits and demerits of top-down and bottom-up inverse approaches (Table 12.2), a matrix that may also be useful and inspiring to other infrastructures, they draw up policy recommendations. These reflect the tension between, on the one hand, the government's need to foster innovation and breed diversity, an outcome more in line with a bottom-up, inverse approach; and, on the other hand, the need for a harmonized and interoperable e-government infrastructure, which requires an orchestrated approach (i.e. designed and centrally controlled). They propose a mix of polices that includes stimulating a modular approach, specifying clear guidelines for self-organization *outcomes* (e.g. user acceptance, reusability), and collecting best practices; but also coordination-oriented policies to avoid duplication of efforts (organizational efficiency, reduce transaction costs), to achieve interoperability (standards-based but not too generic; reference implementations) and to avoid fragmentation. Further research is needed to determine the best mix of policies (Van Veenstra and Janssen).

Herder and Stikkelman are faced with a similar challenge. In their case a 'delicate balancing act' is needed to design the conditions for self-organization of a syngas infrastructure. To this end, they have developed a process that alternates top-down design with the introduction of inverse elements (Chapter 11).

Encoding Incentives in Standards and Technology

Incentives for users to participate, share and collaborate may not only be encoded in policies, regulatory structures and process design, but also in standard specifications and technologies (Maier 1999). Policy makers have as yet paid little attention to the possibilities of integrating value-sensitive design notions (e.g. Flanagan et al. 2008) into their infrastructure policy approach. For example, peer-to-peer networks can encode the tit-for-tat principle in such a manner that if one wants to download content one should at least offer the downloaded content in return (Egyedi et al., Appendix II). Another example: the technology used for the Village Telcos is inclusive in that it is based on a ‘connect-in’ approach, that is, anyone with sufficient means and expertise can access the network. ICT coverage is not decided, as is more common, by the network operator (Westerveld). As a final example, for volunteers who are (also) motivated by building their reputation and seek a stage for their expertise (Verhaegh and Van Oost) the visibility of the revision history in Wikipedia articles (Nikolic and Davis) can be an extra stimulus to contribute. Further study is needed to determine how best to include value-sensitive design principles in infrastructure standards and technologies, and integrate this in policy as it would require policy consistency and long-term planning.

SUSTAINABILITY OF INVERSE INFRASTRUCTURES

To what degree inverse infrastructures can successfully compete with commercial and public centralized service offerings requires more study. Possibly they constitute an alternative in rural areas, where top-down initiated and centralized infrastructure projects often seem to fail (Westerveld; Correljé and Schuetze). Under certain circumstances they possibly also succeed in urban contexts, as city-wide Wi-Fi networks seem to indicate (Verhaegh and Van Oost). Two opposing but plausible lines of reasoning exist. Given that volunteer work often plays a key part in many inverse infrastructures, does this make them less sustainable than infrastructures run by public agencies and commercial companies? Or, conversely, could a locally better embedded inverse approach sooner lead to a sustainable and adaptive infrastructure? The previous chapters shed light on a number of issues pertinent to these questions and on the underlying question of what factors sustain self-organization.

The ham radio service (Vree) and citizen-driven waste paper collection (De Jong and Mulder) illustrate that inverse infrastructures can be stable over long periods of time. In the first case the technical expertise was volunteered by experts working in the field and directly benefiting from collaborating. In the second case their ‘community spirit’ drove citizen volunteers to separate and collect waste paper, albeit with background support from municipalities. In both cases the quality and social fabric of the actor network were influential in securing sustained user involvement. Actors were like-minded.

When actors have heterogeneous interests and different capacities are required to develop an infrastructure, the creation of common ground and shared interactive learning is crucial for the infrastructure's long-term survival, as the Danish case of wind energy illustrates (Kamp). There were close contacts between manufacturers and users of wind turbines, frequent exchanges of knowledge and experiences, and a trial-and-error approach to technology development. But also the organization of windmill owner-users, which negotiated collective buyback tariffs and functional requirements with producers, was important for its sustenance.

Maintenance Incentives

To survive, infrastructure maintenance is crucial (Verhaegh and Van Oost; Westerveld). The lack of attention paid to maintenance largely explains why top-down initiatives to introduce telecommunication in deep rural areas often fail (Westerveld). Verhaegh and Van Oost note that keeping a network running and scaling it up to accommodate more users is not nearly as satisfying as getting it to work in the first place. Nevertheless, in the city-wide Wi-Fi case they analyze, technical volunteers as well as citizen users took up maintenance tasks. The former's motives to do so were similar to those that drove them to contribute in the first place, i.e., the technical competencies of these volunteers were challenged; the maintenance work offered a stage for demonstrating their technical expertise; and succeeding would increase their reputation. An interesting phenomenon not yet observed in other studies, is that also citizen end-users took up maintenance tasks (e.g. as part of the 'failure report system' and actively as Node Adoption Volunteers, Verhaegh and Van Oost). They did so not only because they themselves benefit from free access to Internet but also for reasons of 'caring' and reciprocity.

To relieve volunteers from tedious maintenance tasks they are, where possible, mechanized and automated (e.g. bots for repairs after vandalism and watchlists to monitor changes in Wikipedia articles, Nikolic and Davis; e.g. daily rebooting of vulnerable nodes and self reporting of node software, Verhaegh and Van Oost). That is, next to people, technical solutions also form an important part of inverse maintenance systems. They allow volunteers to focus (more) on what interests them and answers to their intrinsic or extrinsic needs, thereby sustaining volunteer commitment to keep the infrastructure running and evolving.

To continue cooperation those involved must care enough about their future together, Axelrod notes (1984). He centers on cooperation in prisoner's dilemma situations, which often strongly differ from the inverse cooperation situations described in the previous chapters. But the need he identifies for a 'shadow of the future without which cooperation is impossible to sustain' (Axelrod 1984, p. 182) is also relevant for the maintenance and sustainability of inverse infrastructures. Contributors will want to identify with successful projects. This 'shadow' can be elongated by making interactions more durable and more frequent – akin to Kamp's suggestions for enhancing interactive learning for inverse developments in wind energy (Chapter 7).

Different coordinative means are used in parallel to support self-organization in inverse infrastructures (Egyedi et al., Appendix II). Some means are more forceful and impose desirable behavior (e.g. by encoding the need to cooperate in software) and based on authority (e.g. informal leadership); while others aim to entice contributive behavior and/or create a bandwagon effect (e.g. public campaigns for waste paper collection). Egyedi et al. speak of coordination push and coordination pull, respectively. In addition, they distinguish three different 'coordinative moments' in self-organization that help to identify the means of support used in previous chapters. Some means aim at creating a common frame of mind and a shared technological base at the outset (e.g. adopting a standard; input coordination); others help to support the process of coordination in self-organization (e.g. review options in Wikipedia; process design for syngas); and again other means focus foremost on arriving at coordinated outcomes (e.g. compatibility logo; output coordination). In different mixes these types of coordination mechanisms – push and pull, and input, process and output – are needed to build up inverse infrastructures and kindle long-term user involvement and their ongoing commitment.

Hostile or Friendly Contexts

Because inverse infrastructures develop in unconventional ways (uncrystallized ownership volunteer-driven, self-organizing), they are less well-protected and more susceptible to – commercial and/or hostile – takeovers than public or company-owned infrastructures are. This is particularly evident for ICT-based inverse infrastructures. Their openness and lack of ownership make them vulnerable to commercial capture (Vree, personal communication). They can be copied by a commercial enterprise and improved. If they then attract a larger group of participants than the original, it may lead to a complete transition of the original to one or a few owners. This is what seems to happen to the Internet and what has happened to Usenet. Both started out as 'pure' inverse infrastructures, but have slowly been assimilated by a small group of large companies (Vree, personal communication). Similarly, some city-wide Wi-Fi networks have been taken over by commercial operators (see also the FON case in Appendix II). More insight is needed in the dynamics of inverse infrastructure takeovers if we are to take stock of their effects on infrastructure innovation, the services market and users (as consumers and producers).

Sometimes the adoption of inverse initiatives by a central agency is explicitly aimed for. The e-government facilities discussed by Van Veenstra and Jansen (Chapter 12) are meant to be generic building blocks used throughout government IT systems. While those instigated top-down by central government are destined to be used as such and are likely to survive and be sustained top-down, the fate of those developed decentrally by 'users' (local government agencies) is less certain. They must be reusable across IT systems if they are to sustain and be adopted as generic e-government facilities.

Inverse Potential for Developing Countries

Inverse initiatives could play a pre-eminent role in providing access to infrastructures in rural areas where no LTS alternatives exist, and succeed where centralized initiatives have not, Westerveld argues (Chapter 10). He provides two compelling arguments. First, user ownership of infrastructure elements means having a direct stake in high quality and locally relevant content and services, and in sustained service provision. It increases the likelihood of users actively taking on responsibility for its functioning. Second, initiatives rooted in rural communities are better adapted to the local socio-economic context (e.g. poverty, dependence on cheap, easy to install and easily repairable and maintainable technologies, absence of or unreliable power supply). They will therefore more likely lead to viable technical solutions (e.g. asynchronous telecommunication) and business models (e.g. pre-paid communication).

DISTINCTNESS OF INVERSE INFRASTRUCTURES

The degree to which inverse infrastructures can be viewed as separate, bounded objects determines whether specific inverse policies are likely to be effective and successful, and/or whether they can develop relatively unhindered. In this section I reflect on their distinctness and interrelatedness with other infrastructures, issues that are touched upon in most chapters and run as a central theme through some (waste paper collection, De Jong and Mulder; RTV signal reception, Weijers; water supply and sanitation, Correljé and Schuetze).

Interrelatedness of Inverse and LTS

Where a centralized service already exists, inverse developments will affect the incumbent provider either positively (e.g. where rainwater harvesting reduces pressure on sewage system) or negatively (e.g. income of utility drops) (Correljé and Schuetze). Most often they are viewed as competitors that disrupt the status quo. For example, an incumbent South African telecom operator feels Dabba's Telecenter initiative to be a direct threat (Box 10.1; Westerveld); Wikipedia is gaining ground as a source of – also scientific – knowledge and is likely to drive paper-oriented and centrally-coordinated encyclopedias out of business; and voluntary-driven city-wide Wi-Fi's offer free access to Internet, a service which other providers run on a commercial basis.

The possible replacement of LTS-type of infrastructures by inverse infrastructures is only part of the overall picture. They can also live in a symbiotic relationship to the mutual benefit of both infrastructures (see above example of Correljé and Schuetze), or complement each other in different ways. One infrastructure may comprise different subsystems, each providing a different part of the overall infrastructure service. As Weijers (Chapter 4) points out, these subsystems may show different patterns of governance (e.g. decentralized reception and centralized distribution of radio and TV signals). A change in the institutional context (e.g. new regulation that allows mergers between subsystem markets) may fully revise these patterns.

Inverse infrastructures may also be part of a more large-scale, centralized practice in another sense. They arise and operate within a certain techno-material and socio-economic context. For example, in the case of water supply and sanitation systems, they are part of the large hydrological cycle and affect the functioning of the small (i.e. urban) water cycle (Correljé and Schuetze; Chapter 9). Inverse initiatives are therefore likely to affect centrally provided services.

Institutionally, citizen-driven waste paper collection is nested within a large-scale, centralized and partly commercial service infrastructure under government responsibility (De Jong and Mulder). It operates rather independently from the larger – primarily Dutch, but also cross-border – paper recycling infrastructure. The two primary features that distinguish the nested inverse from the larger surrounding infrastructure are the different means of coordination (i.e. self-organization by volunteers versus central control by the municipalities) and degree of professionalism (i.e. paid or unpaid activities). However, while distinguishable, inverse infrastructure-oriented policy must take its nested nature into account.

Inverse stand-alone and small-scale infrastructures can be tied to large-scale ones in other ways as well. For example, they may depend on the latter for back-up (micro combined heat and power, wind energy) or for other crucial functions (e.g. to feed surplus wind-energy into the grid). In the case of DakNet, 'data mules' and motorcyclists provide asynchronous connection between villages and city-based Internet access points (Westerveld); and in the case of Village Telcos, i.e. the small-scale telephone networks emerging in deep rural areas of developing countries, these are designed to allow progressive interconnection with LTS-based telecommunications in the outside world at a later stage.

Same Sector Co-Creation

The number of new services based on combinations of existing ones is numerous. An interesting one is the syngas infrastructure which integrates different fossil energy resources (Herder and Stikkelman, Chapter 11). Some are more loosely coupled infrastructures (e.g. use of the mobile phone as part of e-government authentication; Van Veenstra and Janssen) while others are more tightly coupled (e.g., file transfer over telephone wires, wiki over Internet, Internet connection by air for Wi-Fi). Inverse infrastructures may be stacked. Similar to the Internet, which has been a stepping stone for many higher level inverse infrastructures, the latter may become a stepping stone for further inverse developments. Thus, while wikis run on Internet, Nikolic and Davis foresee that new inverse infrastructures will run on wikis.

Interdependencies between Different Sectors

Technical interdependencies between different infrastructures are plentiful. For example, clearly radio, television and ICT highly depend on the availability of reliable power networks (electricity networks or stand-alone facilities). But also drinking water supply and wastewater management systems often run on electricity. This is a non-trivial issue in rural areas of developing countries, where basic infrastructure provision is mostly lacking. Their absence also hinders inverse developments.

A second example is that in developing countries, ICTs are seen as instrumental for the development of many high-tech (inverse) infrastructures in other sectors (e.g. ICT-enabled smart-grids in the energy sector; Künneke). These and other inter- and cross-dependencies sometimes pave the way for institutional integration in infrastructure service provision (e.g. municipal RTV cable networks that are sold to energy companies, Weijers).

In sum, the situations of competition, interconnectedness and interdependencies between inverse and centralized large-scale infrastructures in the above (sub)sections show that inverse infrastructures cannot be viewed as separate, bounded objects. It means that a policy approach that takes an isolated view on inverse infrastructures is not likely to be effective and lead to the desired outcomes.

DISRUPTIVE INVERSE INFRASTRUCTURES

The inverse phenomenon is creating a new dynamic in the infrastructure landscape. Rooted in widely diverging (local) settings, inverse infrastructures promise to lead to more diverse and innovative service offerings.

Certain inverse features call into question the currently dominant LTS-oriented institutional context and are particularly disruptive. First, given that users self-organize and often do so on an unpaid voluntary basis, infrastructure policies must take into account (a) user behavior based on more complex (self) interests than those of the 'homo economicus' (i.e., include reciprocity and gift-based models of human behavior); and (b) that a more efficient mode of coordination (i.e. hierarchical coordination, which is consistently associated with lower transaction costs) may not be more effective than self-organization.

Accommodating inverse developments will increase the complexity of infrastructure systems. Decentralized and possibly polycentric (Künneke) modes of infrastructure governance will pose new demands on – national, regional and international – infrastructure agreements, policies and regulation. These must become more flexible and robust to cater to multiple and more diverse forms of infrastructure provision (e.g. shared, non-commercial, hybrid ownership conditions). Since processes of trial-and-error, learning by doing and interactive learning rather than blueprints will determine inverse infrastructure developments (Chapters 6, 7 and 11), the outcomes may be unexpected and put to the test existing institutional arrangements (Künneke).

Whereas ownership of and responsibilities in LTS-based infrastructure services are usually clearly circumscribed, in inverse infrastructures they are more ambiguous. Individuals, groups or companies may own part of the infrastructure (e.g. a server), but ownership of other parts may be less clear (e.g. certain open source software; content of Wikipedia). Currently public-private partnerships (PPPs) between infrastructure companies and governments are a common occurrence. Examples are the private railway companies and waste handling companies that operate under (local) government concession. But in the case of inverse infrastructures, initially user-owned infrastructure components may end up being governed by unprecedented partnerships such as those between citizens and local government (public-citizen partnerships) and between citizens and businesses (private-citizen partnerships) in which citizen users participate as non-commercial partners. Whether these partnerships are formalized or remain informal, or whether they are potentially stable or unstable, institutional change will be needed to accommodate them.

Lastly, centralized approaches of governments and companies are often indifferent to specific geographical or otherwise local contexts. They often treat citizens as homogeneous, and tend to render users to passive consumers. Inverse infrastructures, conversely, reintroduce the user in his or her local context as the starting point of infrastructure development and maintenance. By doing so, local knowledge and socio-cultural factors are more easily taken on board (Westerveld). An example is the citizen-driven reintroduction of johads (i.e., collection tanks for rainwater), a traditional technology used in Northern India and well-suited to local geographical circumstances, needs (irrigation, recharging groundwater), and socio-cultural conditions (community ownership) (Correljé and Schuetze). Deliberating infrastructures from the standpoint of user investments, local responsibility for their operation, and local diversity in usage is disruptive in a period in which centralized infrastructure governance views dominate.

Policy Recommendations

The influence of infrastructures is pervasive. As catalysts of both societal and economic prosperity and threats (e.g. warfare and spread of diseases) governments cannot but take a stance on whether inverse infrastructure developments are desirable and deserve support. If so, they will have to diverge from the classical approach. If not government but the general public and private sector are the initial investor in an infrastructure policy makers must move away from using 'the words design, construct and implement' and instead orient policy towards bringing about, causing to happen and creating optimum conditions for (Vree, Appendix I).

Inevitably, there is delay between new infrastructure developments and matching institutional arrangements. As a consequence innocent new practices are sometimes rendered illegal. Weijers' example of radio in the 1920s nicely illustrates this. At the time, the Dutch government banned the transmission activities of radio amateurs and forbade civilians to listen to radio. It treated radio as a new manifestation of radio telegraphy, a technology reserved for the military (Chapter 4). New infrastructural developments, i.e. new technologies, ideas as well as approaches for exploitation or financing must fit into the wider institutional framework (Correljé and Schuetze, Chapter 9). For even in relatively unregulated areas where no infrastructure services exist there are regulations (e.g. radio signals that may not cross borders, Westerveld) and policies to consider (e.g. exclusive concessions for broadcasting, Weijers) that are likely to hinder the emergence of inverse developments.

Policy approach

As is commonly the case, over time the public authorities will bridge the gap between today's technological practices and yesterday's policy configurations, and internalize inverse infrastructure developments (Künneke; Correljé and Schuetze). How will and should they do so? Policy makers have the propensity, expertise and experience to use formal instruments to determine 'the rules of the game'. However, they should be aware of the more informal and autonomous self-organizing nature of inverse infrastructures, which poses extra challenges (Künneke). Government policies sometimes smother the same initiatives they mean to encourage by institutionalizing and integrating them. This may have happened because the policies center on external incentives to support intrinsically motivated individuals, an approach that may undermine rather than support user-driven developments. On the other hand, the case of Dutch waste paper collection shows that governments may successfully 'preserve' an inverse infrastructure for multiple decades (De Jong and Mulder). But the increasingly complex and detailed interventions needed to maintain volunteer involvement – in cities, not in rural areas – may indicate over-involvement. In other words, the best policy might be one of non-interference, although that too can be hazardous (e.g. increasing vulnerability of Internet due to reduced number of service providers). Künneke recommends that, at least where operational infrastructure processes are concerned, governments should be very reticent.

The societal acceptance of inverse infrastructures depends on their impact. Public policy must balance the positive and negative externalities both for user contributors and those not directly involved (Correljé and Schuetze). Public authorities must address the negative effects inverse infrastructures may have on others by setting new rules and requirements, tariff adjustments, etc. They should stimulate positive effects by policies that support and promote decentral approaches. A level playing field must be created that allows inverse infrastructures to develop next to infrastructures of incumbent providers (i.e. low barriers to entry and, where relevant, opportunities for market-based contracting, Künneke). Desirable innovative but vulnerable inverse niches must be safeguarded from an untimely demise. The authorities will want to foster optimal conditions for inverse developments where the need for a local infrastructure is high and cannot be adequately met in a centralized and uniform way; where user acceptance is crucial (e-government, Van Veenstra and Janssen); or where local user involvement serves an important economic or societal purpose (e.g. increase citizen awareness of environmental issues, De Jong and Mulder).

A special policy challenge is posed by the interdependencies between inverse infrastructures and LTSs, between same and different sector infrastructures, and between infrastructure systems and subsystems. It may not be easy to devise internally consistent and coherent policies that address partial dependencies between inverse infrastructures and LTSs in connection. Sometimes their interrelatedness will be evident. However, recognition is more difficult where they are not physically or institutionally connected (examples from infrastructure subsystems are RTV distribution and broadcasting, Weijers; rainwater harvesting and sewage system, Correljé and Schuetze).

Finally, let us return to Van den Berg's view that inverse infrastructures are complex adaptive systems and emerge at the edge of order and chaos (Chapter 2). Furthermore, let us push his ideas to their limit to explore the implications and fuel discussion on infrastructure innovation. *In extremo* the CAS approach entails two main messages:

1. Inverse infrastructures derive from instability; the novelty and innovation they represent arise from a situation of tension and themselves lead to friction with their environment. Knowing this, policy makers will sooner recognize situations in which such inverse infrastructures (are likely to) arise. If desired by society the ultimate counter-intuitive policy consequence might then be to sustain the tension that initially instigated and supported inverse developments.
2. Given their balancing act at the edge of order and chaos, inverse infrastructures will sooner seem to be of a temporary nature; once they stabilize and institutionalize they are more likely to dissolve, be subsumed by another infrastructure or change nature. Passing short-lived infrastructure projects and hypes like Second Life would seem to confirm that. This would mean that government policy must acknowledge the temporary nature of some infrastructures – which is a true paradigm shift given the long lifetime usually associated with infrastructures; and, conversely, that care must be taken not to unduly shorten their lifetime.

In sum, emerging at the edge of order and chaos, inverse infrastructures are in comparison to LTSs more susceptible to external influences and will therefore also show more dynamics. That is, we will need to adapt to the idea of more ad hoc and temporary nature infrastructures in the future. Because of this and their less predefined and more uncertain outcome, they are more likely to require adaptive and robust policies than past infrastructures in order to survive.

Policy research issues

While discussing the conditions for inverse infrastructure emergence, several policy options were noted, such as introducing means to promote interactive learning among heterogeneous actors and economic incentives for citizen investments in inverse technologies (Kamp). Research is needed to study how robust such policy suggestions are in view of the risk of undermining inverse initiatives by putting in place external incentives that mismatch with the intrinsic (self-determination) needs of user-citizens. One of the key issues to explore in further research is what robust inverse infrastructure policy might further entail given the diversity of inverse infrastructures and their settings. The previous chapters indicate that supportive research should (a) focus not only on inverse infrastructure emergence but also on the whole life-cycle, including inverse maintenance (Verhaegh and Van Oost; Westerveld); (b) address the policy implications of infrastructure users becoming (co-) producers; and (c) analyze the circumstances under which ‘universal service’ provisions remain desirable and what role inverse infrastructures could and should play in this respect. To what degree can inverse infrastructures replace public utility infrastructures and guarantee, for instance, security of supply, universal service and acceptable pricing schemes?

Research is needed on how competing local and centralized initiatives may reinforce or hinder each other and what coherent policies for intertwined and complementary infrastructures should look like. Since inverse institutional developments need yet to crystallize, government policy should create room for institutional experimentation with forms of self-governance and diffuse ownership structure – and be prepared for new kinds of partnerships (other than PPPs; see earlier). Going one step further, to enable self-organization Künneke recommends that government should stimulate experimentation and variety in institutions and technological practices, and explore the opportunities that polycentric systems offer (e.g. a polycentric context would accommodate locally different regimes).

With the advent of inverse developments, policy will need to deal not only with an increasingly complex infrastructure landscape, but also with elements that are disruptive to the institutional setting of which policy itself is part. This makes user-driven and self-organized infrastructures an unsettling source of change.

NOTES

1. References in the text that refer to a chapter or appendix, or to a source with mentioning the year of publication all refer to chapters in this volume.
2. Close relatedness of players (e.g. kinship) permits true altruism (sacrifice by one individual for the benefit of another) and increases the viability of reciprocal cooperation (Axelrod, 1984, p. 96, p. 98).
3. Wikipedia, Self-determination Theory, consulted 12 May 2011.

REFERENCES

Axelrod, Robert (1984), *The Evolution of Cooperation*, New York: Basic Books.

Brafman, Ori and Rod A. Beckstrom (2007), *The Starfish and the Spider: The Unstoppable Power of Leaderless Organizations*, London: Penguin.

Chesbrough, Henry (2003), *Open Innovation: The New Imperative for Creating and Profiting from Technology*, Boston: Harvard Business School Press.

Deci, E.L. (1971), ‘Effects of externally mediated rewards on intrinsic motivation’, *Journal of Personality and Social Psychology*, **18**, 105-115.

Deci, E. and R. Ryan (eds) (2002), *Handbook of Self-Determination Research*, Rochester, New York: University of Rochester Press.

Flanagan M., D.C. Howe and H. Nissenbaum (2008), 'Embodying values in technology. Theory and practise', in J. van den Hoven and J. Weckert (eds), *Information Technology and Moral Philosophy*, Cambridge: Cambridge University Press, pp. 322-353.

Gell-Mann, M. (1994), *The Quark and the Jaguar: Adventures in the Simple and the Complex*, New York: Freeman & Co.

Holland, J.H. (1995), *Hidden Order: How Adaptation Builds Complexity*, Reading, MA: Addison-Wesley.

Maier, M.W. (1999), 'Architecting principles for systems-of-systems', *Systems Engineering*, **2** (1), 267-284.

Oudshoorn, N. and T. Pinch (2008), 'User-technology relationships: some recent developments', in E.J. Hackett, O. Amsterdamska, M. Lunch and J. Wajcman (eds), *The Handbook of Science and Technology Studies*, Cambridge, MA: MIT Press.

Raymond, Eric S. (1999), *The Cathedral and the Bazaar*, Sebastopol, CA: O'Reilly.