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Strategic standardisation of smart systems: A roadmapping process in support of innovation

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ABSTRACT

With increasing awareness among policymakers and other stakeholders of the importance of standards in supporting innovation, many national governments and standards organisations are taking strategic foresight approaches to standardisation. This is especially the case for ICT-based '*smart systems*', where an increasing number of different technologies and systems are interconnected to each other, involving a complex variety of actors. Roadmapping is a widely used tool to support such strategic policy processes, yet there remain significant challenges in terms of structuring and managing roadmapping exercises. This paper proposes a systematic process of managing roadmapping practices to develop effective strategies for standardisation in support of innovation. Based on literature regarding public-level strategy roadmaps and reviews of existing standardisation roadmapping exercises, a more systematic process has been developed, incorporating activities and tools to address increased challenges associated with standardisation in such complex areas. The findings of the research not only provide guidance on how roadmapping processes can be structured and organised to more effectively address standardisation issues in innovation strategies for smart systems, but also highlight policy implications, including potential roles for government in supporting standardisation efforts.

1. Introduction

With the growing importance and pervasiveness of Information and Communications Technology (ICT), there has been increasing awareness of the importance of standards for ICT innovation since the last decades of the 20th century. The proliferation of various technical components that need to be interconnected within larger systems presents associated standardisation challenges, requiring more anticipatory standards to achieve interoperability among networked products (Blumenthal and Clark, 1995; David and Shurmer, 1996; Jakobs et al., 2011). Many studies have been carried out, exploring important roles of standards in supporting technological innovation, including: defining and establishing common foundations upon which innovative technology may be developed; codifying and diffusing state-of-the-art technology and practices; and allowing interoperability across products and systems (Allen and Sriram, 2000; Tassey, 2000; Blind and Gauch, 2009; Swann, 2010; NSTC, 2011). While timely and well-designed standards can support innovation, premature or inappropriate standards may have detrimental impacts on innovation, including: imposing constraints by increasing irreversibility and decreasing flexibility, locking in inferior standards or technologies (e.g., the QWERTY keyboard), and risking monopolies, especially in network industries where standards can become technological bottlenecks (David, 1985; Shurmer and Lea, 1995; Hanseth et al., 1996; Swann, 2000; Langlois, 2001; CIE, 2006).

Because of this dual nature of standards, strategic approaches for timely and appropriate standardisation are critical for innovation systems. However, this is especially challenging for complex systems integrating different technologies and subsystems, as they require not only a large infrastructure of interconnection standards, but also input from a variety of stakeholders from different organisations and disciplines (Blumenthal and Clark, 1995; NPE, 2012; Tassey, 2014). These systems are also continuously evolving, based on new R&D-driven innovations in individual components and technologies. Furthermore, the pervasiveness of smart ICT-based systems in areas of critical national and societal importance – including energy (e.g., smart grids), transportation (e.g., smart mobility), and industrial productivity and competitiveness (e.g., smart manufacturing) – results in an even greater variety of stakeholder interests, regulatory issues, and policy considerations. Consequently, a more systematic and anticipatory approach to strategic standardisation is called for, particularly in complex heterogeneous areas of '*smart systems*[1]' where ICT plays a critical role.

The need for more systematic foresight approaches to standardisation has been widely recognised among policymakers and standards

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[1] Although definitions vary, the term '*smart systems*' used in this paper refers to systems that, by incorporating a wide varieties of networked digital computing and communication technologies, are able to detect, analyse, and respond to the environment in performing smart actions (NIST, 2010a; TTA, 2013; DKE, 2014).

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organisations (EXPRESS, 2010; NSTC, 2011; European Commission, 2011). In order to address such challenges, there have been a number of future-oriented analyses for effective anticipation and management of standards. Roadmapping is one of the most widely used tools for such foresight exercises, supporting systematic planning and development of standardisation strategies. Many countries have developed standardisation roadmaps in various areas related to smart systems, as there are significant challenges and opportunities associated with standardisation in these complex areas (e.g., NIST, 2010a; Hogan et al., 2011; NPE, 2012; DKE, 2012, 2014; TTA, 2013; Scapolo et al., 2014). Despite its wide adoption, there remain considerable challenges for policymakers and standards organisations in terms of how to structure and manage roadmapping for strategic foresight analyses of standardisation. Although recent work by Featherston et al. (2016) presents a framework to support the anticipation of standards with careful characterisation of various technologies and innovation activities relevant to standardisation, more research is needed to develop a systematic process of organising and managing roadmapping exercises, which effectively engages and coordinates between various stakeholders and Standards Development Organisations (SDOs).

In this regard, this paper proposes a more systematic and structured process model for managing roadmapping exercises to support effective standardisation in highly complex heterogeneous areas of smart systems. We begin by reviewing the existing literature on general strategic roadmapping processes. It is followed by case studies of existing standardisation roadmapping exercises, exploring the applicability of these processes and identifying key issues and challenges associated with standardisation in smart systems. This review of existing practices provides further insights into detailed activities and tools that are perceived by practitioners to be effective in addressing some of these issues, illustrating systematic processes of organising, managing, and governing multi-stakeholder, multi-disciplinary standardisation roadmapping exercises. We conclude by discussing the implications of our findings for how roadmapping processes might be better structured and managed to effectively address standardisation issues in innovation strategies for complex areas of smart systems.

2. Literature review

The most commonly used definition of standards is provided by the International Organisation for Standardisation (ISO), which defines a standard as"*… a document*, *established by consensus and approved by a recognised body*, *that provides*, *for common and repeated use*, *rules*, *guidelines or characteristics for activities or their results*, *aimed at the achievement of the optimum degree of order in a given context*" (ISO/IEC, 2004; cited in Andersen, 2013, p. 80). Standards and standardisation are explored in various domains and disciplines with different perspectives (Lyytinen et al., 2008; Narayanan and Chen, 2012). In the following sections, we give a brief overview of selected academic and practice literature, focusing on important standardisation-related factors to be accounted for in strategic foresight analyses for technological innovation. In particular, we draw on this review to develop insights and an initial conceptual framework for structuring our case study analyses of standardisation roadmapping activities in smart systems.

2.1. Roles of standards and standardisation

The systematic perspective on innovation has made many scholars and policymakers aware of importance of standards as powerful institutional mechanisms that shape technological change and innovation; a variety of roles and functions of standards in innovation are thus emphasised by various innovation literature (Porter, 1990; Lundvall, 1992; Ehrnberg and Jacobsson, 1997; Smith, 1997; Allen and Sriram, 2000; Tassey, 2000; Bergek et al., 2008; Swann, 2010; NSTC, 2011). By providing a systematic and integrated perspective of understanding activities and key factors that influence innovation (Edquist, 2001), the '*functions*' of innovation systems approach appears to be particularly useful in analysing the innovation roles of standards in a structured way. Focusing on dynamics of what is actually happening in overall innovation systems, it can also help identify potential system failures, providing rationales for policy interventions in strategic management of standardisation. By looking at how standards are accounted for in literature adopting functions of innovation systems, it is noted that standards are particularly linked to certain functions proposed by Bergek et al. (2008): legitimation, influence on the direction of search, development of positive externalities, and knowledge development and diffusion. Other literature discussing standards in the context of innovation are also reviewed, and factors corresponding to these functions are identified for coherent analyses on various roles and functions provided by standardisation in supporting innovation systems.

2.1.1. 'Legitimation' function of standards

Legitimacy is considered to be a prerequisite for new innovation systems to occur, providing it with appropriateness and desirability so that resources are mobilised and demand is formed (Bergek et al., 2008). Standards provide this legitimacy in two main ways. First, acting as signposts, they reduce social uncertainty and stimulate interactive learning activities by providing and communicating necessary information (Lundvall, 1992; Van de Ven, 1993; Edquist and Johnson, 1997). They not only reduce innovators' uncertainty about the future, encouraging them to engage in innovation, but also increase buyers' acceptance of, and confidence in, new technologies, thereby facilitating market growth and allowing subsequent innovation (Foray, 1998; CIE, 2006; Blind and Gauch, 2009; Swann and Lambert, 2010; European Commission, 2011). Second, a consensus process of setting standards increases social acceptance, by managing and mitigating conflicts that may arise between different approaches (Carlsson and Stankiewicz, 1991).

2.1.2. 'Influence on the direction of search' function of standards

By helping transmit information about what routines are acceptable and providing incentives for engaging in certain innovation activities, standards have significant influence on the behaviour of actors, guiding learning activities and directions of search (Edquist and Johnson, 1997; Smith, 1997). Standards also provide important technical guidance, by not only stating a target level of quality and providing some direction on how to achieve the target, but also articulating customers' demands and making them readily accessible to producers (Mansell, 1995; Bergholz et al., 2006; Swann, 2010; Hogan et al., 2015). Moreover, as results of converging processes towards dominant designs or specific technologies among competing possibilities, standards have significant influence on guiding the allocation of resources and other innovation efforts in certain directions, facilitating the function of 'resource mobilisation' (Porter, 1990; Lundvall, 1992; Van de Ven, 1993).

2.1.3. 'Development of positive externalities' function of standards

Standards can develop positive externalities in the form of network effects – i.e., benefits to users of a system rise with increasing number of users (Smith, 1997) – increasing the attractiveness for customers and leading to rapid diffusion of innovations (Ehrnberg and Jacobsson, 1997). Such externalities encourage actors to participate in other functional activities such as 'knowledge development and diffusion' and 'market formation', strengthening the overall functionality of the system (Bergek et al., 2008). For example, variety-reduction standards foster the diffusion of new products and technologies by allowing the exploitation of economies-of-scale (Blind and Gauch, 2009); measurement standards also help develop economies-of-scale by enabling advances in process control (Swann, 2010). In addition, compatibility and interface standards generate positive network externalities by establishing successful linkages between various components and