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Effects of standardization on the evolution of information and communications technology

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ABSTRACT

Many studies have suggested that standardization inhibits technological change via lock-in effects. However, the negative side of standardization has been overemphasized because of insufficient empirical evidence. On the basis of the standard and triadic patents registered during 1977–2010, this study examines the associations between standardization and technological evolution in the information and communications technology (ICT) industry. We apply the annual International Patent Classification co-occurrence network to Telecommunications, Computers & Machinery, Consumer electronics, and Other ICTs to measure technological evolution with respect to diversity, openness, and concentration. Consequently, we regressed each aspect of technological evolution against the polynomial distributed lag number of the registered ICT standards per annum. The findings suggest different degrees of associations between standardization and technological diversity, openness, and concentration across each area. We observed that technological diversity increases with technology standardization in telecommunication and consumer electronics. In addition, there is a long time-lag effect on technological diversity in Computer & Machinery. Conversely, negative associations with diversity were observed in Other ICT. No significant associations were found between technology standardization and openness or concentration. These findings support the positive side of technology standards, which can offset the claimed lock-in effects.

1. Introduction

The information and communications technology (ICT) industry, including Telecommunications, Computers & Machinery, Consumer electronics, and Other ICT areas, has continuously experienced technological evolution (OECD, 2008). One remarkable phenomena in the ICT industry is standardization, which was accelerated in Europe and the U.S. in the 1980s and reached its peak in the mid to late 1990s (Bekkers and West, 2009; Blind and Gauch, 2008; Gandal et al., 2003; Jho, 2007). Many previous studies suggested that standardization inhibits technological change and may restrain technological development (Blind and Gauch, 2008) via lock-in effects, which potentially hinder the adoption of new, nonstandard technologies. Standardization may also restrict technological openness, which represents the extent to which technological change is open to new technologies, because the lock-in effect prevents timely updates to meet technological change (Bekkers and Martinelli, 2012). Standardization would therefore concentrate technologies around standard technologies.

However, the negative side of standardization has been overemphasized because of insufficient empirical evidence (Narayanan and Chen, 2012). The overemphasized negative aspect can even be offset by the advantages of standardization, such as interoperability, compatibility, efficiency, and cost reductions (Blind et al., 2010; Goluchowicz and Blind, 2011; Lerner and Tirole, 2015; Reddy, 1990; Tassey, 2000). Technology standardization can further trigger the generation of diverse technologies. Standardization and its association with technological evolution have received scant attention in theoretical and empirical studies despite their importance (Lerner and Tirole, 2015). Their co-increasing trend implies that they could have a positive association. Such an association could vary regionally and over time in ICT because the various sub-areas in ICT have experienced radical change. It is thus necessary to properly examine how standardization can be specifically associated with technological change.

We empirically test this relationship in terms of technological diversity, openness, and concentration and represent technological evolution using the ICT standard and related triadic patents registered during 1977–2010 at ICT. We analyzed patents for standardization because standardization in ICT is strongly associated with standard essential patents (Han and Sohn, 2016; Lerner and Tirole, 2015). In this paper, we apply the annual International Patent Classification (IPC) co-occurrence network to measure technological evolution with respect to diversity, openness, and concentration. Technological diversity is

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measured using the Shannon entropy on the IPC co-occurrence networks of the ICT, technological openness is measured via their transitivity, and the degree of technological concentration is measured using the Herfindahl–Hirschman index (HHI) of the centralities on these networks (Eagle et al., 2010; Gauch and Blind, 2015; Kali and Reyes, 2007; Leydesdorff and Rafols, 2011; Louch, 2000; Masisi et al., 2008; Selfhout et al., 2010). Consequently, each aspect of technological evolution is regressed against the polynomial distributed lag number of registered ICT standards per annum.

This paper is structured as follows. Section 2 reviews previous studies of standardization and technological evolution, patent analyses, and related research. Section 3 introduces our research framework along with the data and methodology. Section 4 reports the results of the empirical analyses. Drawing on the analytical findings, Section 5 offers policy implications for technological diversity and standardization management.

2. Literature review and research questions

This section reviews the effects of standardization on ICT, where rapid technology changes and standard technology are important issues. In particular, we examine the technological evolution associated with standardization and outline research issues related to these subjects. In this paper, we conduct a macro level analysis to investigate the association between standardization and technological evolution in ICT. According to Narayanan and Chen (2012), technology standardization can be categorized into the theoretical streams of natural-selection view, collective-action view, system-structural view, and strategic-choice view, with two dimensions, namely levels of analysis (macro/micro) and the research's relative emphasis on assumptions concerning human nature (deterministic versus voluntaristic). Of these, this paper mostly considers the collective-action view, where the collective actions of firms are thought to affect the technological phenomenon and the macro-level outcomes in industry. The collective-action view focuses on how the collective action of a population of firms can generate change in an industry (Narayanan and Chen, 2012). Because it is adopted in an area with standards in complex technological systems or open source standards, we consider that the collective-action view can be applied to ICT. The emergence of a standard can be thought of as the collective actions of firms that are dominant in the technological regime, which can affect both technology standards and innovation performances.

2.1. Standardization and evolution in ICT

We begin with a discussion of technological change, arguably the trigger for technological evolution and standardization. The evolution and standardization of technology can be closely associated since technology consists of various sub-technologies and technological change can be based on the interactions of these technologies. Standardization is necessary for various technologies to be compatible (Jiang et al., 2014; Markard and Erlinghagen, 2017). Technological evolution can be defined as the process of technological change and development through the interactions among technologies (Devezas, 2005). According to Dosi and Nelson (2010), technological change is widely considered to be an evolutionary process, with previous studies into industrial dynamics and economic growth adopting the same perspective. Safarzynska and van den Bergh (2011) demonstrated technological change via an evolutionary approach, and Safarzynska et al. (2012) expanded this view into a general framework to analyze complex dynamic systems containing diverse entities.

Standardization is the process of implementing and developing technological standards based on the consensus of various parties such as firms, institutions, standards organizations, and governments (Xie et al., 2016). Technological changes can then be managed using standardization (Tassey, 2000). Technology standardization accelerated in the 1980s and peaked in the mid- to late 1990s (Bekkers and West, 2009; Blind and Gauch, 2008; Gandal et al., 2003; Jho, 2007). In this study, we consider technology standardization to be the yearly change in standard patents. Standardization is further considered to be the process wherein the IPC of standard patents and other technologies around those IPCs appear and evolve annually (Han and Sohn, 2016). Technological evolution can be thought of as an important facet in technological standardization (Lerner and Tirole, 2014; Lerner and Tirole, 2015; Narayanan and Chen, 2012).

A negative association between standardization and technological change has mainly been found by previous studies. These negative aspects were mostly investigated by concentrating on the technological change among various perspectives of technological evolution. Although studies of the relationship between standardization and technological evolution exist, they conducted interviews or carried out qualitative analysis with a narrow scope. The evidence provided was thus insufficient. While theoretical analyses have been conducted, more follow-up studies are necessary (Bekkers and West, 2009).

Indeed, the standardization and evolution of ICT are increasing. However, their association remains controversial in the literature and it is necessary to reexamine the association between the standardization and evolution of ICT quantitatively. This study reexamined their relationship from the perspective of the collective action view that assesses technological standardization as a result of the interactions of sub-technologies and evolution, measured in terms of diversity, openness, and concentration. Technological evolution is considered as the repeated process of variation and retention leading a dominant technology to emerge from diverse technologies and open environments (Devezas, 2005). Technological evolution is therefore analyzed in terms of technological diversity, openness, and concentration to observe such ICT variations and retentions. Because there are constantly new introductions of various technologies, and non-ICT technologies flow into ICT, we consider technological diversity, along with technological openness, because diverse technologies can lead to an open ICT environment. We examine technological concentration because dominant technologies can emerge and intensify through evolution. We then consider the evolutionary aspect of technological diversity, openness, and concentration to discuss how differently technological evolution relates to standardization by ICT areas and multiple time lags.

We define technological diversity in terms of the number of different technologies in an ICT domain. Leoncini (1998) analyzed long-term technological change, innovation, evolution, and technology systems, emphasizing that diversity in technological systems is important for technological evolution, which is also a fundamental issue for economies experiencing technological change (Mulder et al., 2001). As Geels (2002) noted, technological evolution is a process of variation, selection, and retention and is therefore necessary for technological variation. Devezas (2005) proposed the Evolutionary Theory of Technological Change as a theoretical framework to analyze technological evolution.

Technological openness is the tendency for firms to adopt other technologies (Almeida and Fernandes, 2008). Such firms' actions can be considered from the collective-action view, and technological diversity then becomes important for technological evolution. Previous studies have analyzed whether this has positive associations with technological innovation. Drechsler and Natter (2012) stipulated that the degree of openness is a key factor underlying innovation efficiency and the effectiveness of firms and that it can be agglomerated into the collective-action perspective. Furthermore, they emphasized corporate interaction with external parties, arguing that greater receptivity to openness enhances performance. Externalities from technological openness can affect corporate innovation by enabling diffusion and competition (Lerner and Tirole, 2014; Roper et al., 2013).

Finally, we consider the degree of technological concentration as the lock-in effect on technological evolution. Previous studies into concentration dealt primarily with geography, markets, and industries,