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Interplay of innovation and standardization: Exploring the relevance in developing countries

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ABSTRACT

A growing body of literature recognizes the positive interplay between innovation and standardization. International organizations such as OECD and WTO also increase support for developing countries in building capabilities in innovation and standardization. Yet the relationship between innovation and standardization in developing countries, characterized by relatively weaker technological, economic and institutional capacities, remain under-researched. We review 63 articles extracted from the Web of Science database covering the innovation-standardization nexus in the context of developing countries. We discuss whether and how the relationship between innovation and standardization provides implications for the socioeconomic development in developing countries, and draw a conceptual model to understand the dynamics. Our result shows that standards facilitate innovation in three ways: innovation by scaling, proving and coordinating. While inducing and blocking mechanisms are at play, various stakeholders are involved in the relationship. Among them, the roles of the government and the technology/industry support organizations are highlighted, as they complement the relatively weak technological capabilities of other actors. In contrast to the existing literature on developed countries where standardization is depicted as a dynamic process to shape the innovation path, the current discussion on developing countries is skewed toward the adoption aspect of standards. We also suggest that there is a chasm between the goals of economic growth and those of social development.

1. Introduction

Recently, the increasing observation that innovation and standardization accompany each other in technology development has spurred research on their relationship. A renewed attention is given to the interplay between innovation and standardization, challenging the conventional view (for example, see Maxwell (1998)) that the two are at variance with each other. Even though far from conclusive, literature suggests that their synergetic relationship brings about economic benefits; standards feed information for innovation, accelerate diffusion of innovation, and reduce risks and time to market of innovation (Blind, 2013a; Tassey, 2000). Moving away from the economics to a broader domain of public service, some research begins to explore how standardization may induce innovation as a pathway to gain society-wise learning and to address societal challenges. Standardization is considered as a policy tool to tap into the "social potential" (Drucker, 1984) of innovation, expanding the concept originally conceived by Schumpeter (1934) as an economic advantage.

An important implication arising from such renewed scholarly and emerging policy attention devoted to the relationship between innovation and standardization is associated with developing countries.[1] In the ever-integrating global value chain, the scope of innovation and standardization—mainly the process of development and the impact—spans transnational boundaries. Markedly under the multilateral trade regime, developing countries have become

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[1] *Development* is a contested notion both theoretically and politically (Avgerou, 2010). Accordingly, the use of the term 'developing countries' and the attempt to define their scope also involve complications arising from different theoretical perspectives towards "development" which, in turn, characterizes the key attributes of such a classification. In this paper, the purpose of classification does not lie in identifying a comprehensive list of developing countries; rather, it is more focused on embracing multiple dimensions of development—economic as well as social (Sen, 2000)—that define the scarcity of a variety of resources faced by developing countries.

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active adopters of innovation in forms of standards, and in limited examples, aspiring producers of the innovation-standardization dynamics. In the absence of other strong regulatory systems and benchmarks for trans-border comparison, it has become a common practice for firms and governments in developing countries to adopt international standards and certificates for quality, safety, or sustainability as a signal of competence and innovation (Henson et al., 2011; Vieira and Traill, 2007). Furthermore, the rise of developing countries as key actors in international business, politics and technology has renewed attention to their strategies of innovation and standardization; the case specifically strengthened by the stellar performances of China and other BRICS countries (Lee and Oh, 2006). Last but not least, a number of initiatives have emerged recently at the scene of development practice, designed to support developing countries building capacities in areas of innovation and standardization (OECD, 2012; WHO et al., 2013).

However, due in part to the still nascent nature of the field, the absolute volume of scholarly works highlighting the context of developing countries at the intersection of innovation and standardization is small (for a recent example, see Ernst et al. (2014)). Findings from the current body of research have only limited explanatory power to understand how actors from developing countries affect and are being affected by the interplay, as most of the research draws on the experiences of advanced economies. Setting the focus on developing countries, in this sense, is relevant to a more comprehensive understanding of the dynamics between innovation and standardization. Just as significantly, this paper explores important yet under-researched implications of the relationship of the two that are specific to the socioeconomic needs in developing countries.

Building on this reflection, this paper aims to provide a review of current literature on the innovation-standardization nexus in the context of developing countries. In particular, we are concerned with how the recent academic attention given to the relationship between innovation and standardization finds its relevance in the developing countries in terms of economic and social implications. In doing so, we identify key topical areas and implications for further study in this increasingly important and multidisciplinary field.

This paper is organized in the following manner. We first provide a background by reviewing significant research strands from extant literature. In Section 3, we present the methodology, followed by Section 4 which provides a classification of the current literature. Section 5 discusses the findings and implications and we conclude in Section 6.

2. Contextualizing the relationship between innovation and standardization

2.1. The relationship: innovation and standardization, a paradox revisited

Literature on the innovation-standardization nexus reports that the relationship between the two may occur in two directions; standards and standardization contribute to the creation and the diffusion of innovation (Goluchowicz and Blind, 2011; Tassey, 2000). First, in line with the more traditional view, standards and standardization facilitates the diffusion of innovation. Standards as a set of technical specifications constitute a shared basis of advanced technological knowledge, refined in an easily transferrable form for a widespread adoption (Allen and Sriram, 2000). Standardization as a process of standards development offers critical junctures to build a focus of an emerging technology, which in turn facilitates the diffusion of innovation by increasing the economies of scale and the network benefits (Swann, 2000). Blind (2002) also recognizes the significance of *de jure* standardization as a diffusion channel of innovation. Second, standardization is considered an increasingly important tool to drive innovation in an extended process that encompasses both the creation and implementation of innovation. This view, challenging the traditional perception of standards as being obstructive to innovation due to the "technology-freezing" characteristic, focuses on how standards can seamlessly connect and coordinate the innovation process, which is often laden with complexity and uncertainty. Notably, Blind and Gauch (2009) show how different types of standards facilitate innovation in particular stages of the R&D process.

In extension to the latter perspective that acknowledges the role of standards through the entire process of innovation, Blind (2013a) identifies four types of standards and their effects on innovation. Even though he cautions that a standard does not necessarily serve a single function and thus does not exclusively belong to a single category, his taxonomy according to standards' unique economic functions is useful for theoretical development. They include variety reduction standards, minimum quality standards, compatibility standards, and information standards. Variety reduction standards, by defining specifications of products and services and reducing the production variety, help firms attain economies of scale and critical mass for market success. Minimum quality standards reduce uncertainty and risks coming from the circulation of inferior goods in the market, thereby building consumer trust on new, innovative products. This leads to reduced transaction costs for a broader diffusion. Compatibility standards are central to achieving network externalities and avoiding lock-ins in old technologies. Information standards, by providing a common understanding of technological knowledge among standards users, reduce transaction costs and facilitate trade.[2]

On the whole, the current body of literature recognizes a positive interplay between innovation and standardization. It highlights how standards and standardization play an increasingly important role in shaping the direction of innovation, which goes beyond the passive role as a conduit of innovation diffusion. However, despite the burgeoning discussion, the fact that these findings are mostly drawn from the experiences of advanced economies significantly limits the applicability in developing countries. Building on these findings, we highlight the context of developing countries in the section following.

2.2. The context: developing countries in innovation and standardization studies

In the paucity of literature that explores the innovation and standardization link in developing countries, the departure point can be found from a review of how the contexts of developing countries are addressed in two separate camps of literature, one on innovation and the other on standards and standardization.

The tradition is stronger in innovation studies where an established community of scholars examines technological innovation as a catalyst to economic development (Crane, 1977; Crespi and Zuniga, 2012). In particular, the national innovation systems (NIS) approach provides a useful framework to understand the gaps in the achievement of innovation in different countries (Edquist, 1997; Freeman, 1995; Lundvall, 2007; Nelson, 1993). Even though the concept was originally coined to explain cases of advanced economies, the core of its argument that the knowledge links built through the interactions among different institutions and actors within the system are crucial to innovation also resonates well in the context of developing countries (Intarakumnerd et al., 2002;

[2] Information standards are usually treated as a different category from the other three types of standards. As Blind (2013b) mentions, an information standard usually functions as a combination of different types of standards. For example, a standardized product description as an information standard in itself is an expression of a product variety, and may entail a statement of certain quality requirements of a product that would facilitate its compatibility and interface with other entities.

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Lundvall et al., 2009).[3] As the previous literature on NIS of several developing countries exhibits, one of the primary issues in developing countries is the fragmentation of key institutions, marked by "low capabilities and weak linkages" with some of the strong elements in the system (Liu, 2009, p. 121).[4] Under the NIS framework, standards and standardization are usually addressed as one of the norm-setting institutions called metrology, standardization, testing, and quality (MSTQ) organizations, which, combined together, constitute an essential technological infrastructure in the innovation process (Edquist, 2004). Similar to other functions in NIS, the MSTQ functions in developing countries tend to differ from those in developed countries (Oyelaran-Oyeyinka, 2006). However, the main NIS literature seldom pays attention to the actual process of the MSTQ functions, as it focuses more on the institutional structure of the constituting organizations (Jasmina, 2007). For this reason, the relationship between innovation and standardization is also approached based on the structural characteristics of key institutions, rather than on the different processes and patterns of interplay between the two.

From the literature on standards and standardization, the issue of developing countries is often analyzed in relation to the emergence of international standards as a new mode of transnational regulation. Even though the results are still ambiguous, this stream of research highlights the trade-facilitating effects of international standards, for example, as embodied in the World Trade Organization (WTO) Agreement on Technical Barriers to Trade (TBT Agreement) and the Agreement on the Application of Sanitary and Phytosanitary Measures (SPS Agreement) (Jansen, 2010; Maertens and Swinnen, 2009). Similarly, the diffusion of voluntary international standards and certificates for safety, quality and sustainability poses an opportunity for firms in developing countries to raise their productivity and sales performance (Goedhuys and Sleuwaegen, 2013; Henson et al., 2011) and to increase access to international markets (Mergenthaler et al., 2009). However, due to its focus on trade, the extant research is largely confined to the analysis of quality standards and certificates in the agricultural sector, a major export industry for many developing countries, while paying little attention to other types of standards in different sectors. Therefore, the analytical linkage to innovation is also limited, lacking ground-level analyses on how different types of standards and their development may influence the innovation process in developing countries.

Combined together, while these two camps of research exhibit a wide spectrum of perspectives, there is a certain overlap in the ways in which developing countries are addressed in the innovation and the standardization studies. First, in both studies, innovation and standardization have become increasingly important to the sustainable economic growth of developing countries particularly under the context of global economic integration and competition. Second, similar to the literature on advanced economies (Furman et al., 2002), it is the combination of the institutional strength of the country and the capabilities of individual actors that either enable or hinder the innovation or standardization processes. However, in both camps of research, the dynamic interplay between standards/standardization and innovation including the different patterns of and the conditions under which the two relate each other is not fully explored. Given that, in the sections following, we continue with two questions in mind: first, whether and to what extent different types of standards have varying impacts on innovation, and; second, what are the key elements in the institutional conditions of a country that affect the innovation-standardization relationship.

3. Methodology

Reviewing an emerging field of study where literatures from different academic disciplines co-exist is a difficult task. Definitions of key terms are fuzzy across the fields, and the methodological approaches and theoretical backgrounds tend to be siloed and inconsistent to draw out a clear pattern of findings. In addition, it runs the risk of presenting an incomprehensive picture of a multidisciplinary field. Hence, a methodological rigor is required in the collection and the interpretation of the literature. We employ the systematic literature review as a method to review literature according to a transparent, comprehensive and reproducible methodology (Tranfield et al., 2003). We follow Tranfield et al.'s (2003) three-step approach, consisting of planning, execution, and reporting.

The first step, planning, entails the identification of the research objectives and the selection of data sources and search protocols. As mentioned, a particular purpose of this review is to understand the varying influence of standards and standardization on innovation in the context of developing countries, and to draw out a conceptual model of the conditions under which these relationships stand out. Considering the relatively short history of research on this topic, our goal for the data scanning is to be comprehensive in terms of the disciplinary scope and open in terms of the research outlets, encompassing peer-reviewed journals as well as conference proceedings. Based on these criteria, we choose the Web of Science (WoS) database core collection for our data source. WoS is one of the most widespread databases covering different scientific fields, including not only peer-reviewed citation databases but also conference-proceedings citation for comprehensive search results (Chadegani et al., 2013).

In the second step, execution, we collected, organized, and processed the data. Queries have been made to identify articles that contain all of the following keywords, 'standard*', 'innovat*', and 'developing countr*' (Fig. 1). In order to capture broader standards-related activities in developing countries such as certification, an additional query has been made using the keyword 'certif*' in place of 'standard*'. For the keyword 'developing countr*', additional queries have been made using alternative search phrases such as 'emerging countr*', 'developing econom*', and 'emerging econom*'. This initial search has returned 232 articles. Next, a quality assessment of the preliminary pool has been conducted to identify the relevance and availability of each article to the purpose of this study. Articles that are not accessible,[5] from natural and medical science fields,[6] and that use the terms for other concepts[7]

[3] Lundvall et al. (2009) note that there are two different perspectives of understanding NIS: a narrow definition in which innovation is confined to the development of scientific and technological knowledge, and a broader one in which innovation entails an extensive process of learning and competence-building. While the first perspective provides a relatively clear-cut definition of innovation indicating the result of R&D, innovation in the second category is defined as "a continuous cumulative process involving not only radical and incremental innovation but also the diffusion, absorption and the use of innovation" (p.120). Considering that innovation in developing countries derives from non-R&D based activities, we take the broad perspective of NIS for the rest of this paper defined as "an open, evolving and complex system that encompasses relationships within and between organizations, institutions and socio-economic structures which determine the rate and direction of innovation and competence-building emanating from processes of science-based and experience-based learning (Lundvall et al., 2009, p. 6)."

[4] NIS-based research on successful emerging economies such as China (Liu and White, 2001) shows that the key knowledge links built under the strong leadership of the government allow intensive technological learning to take place in the NIS, which eventually leads to indigenous innovation. However, in less successful cases of developing countries, for example, Thailand, the lack of autonomy and competence of the government contributes to the "perpetuation of weak and fragmented" NIS (Intarakumnerd et al., 2002).

[5] Some of the conference proceedings are not accessible from the academic databases.

[6] Fields from medical science include, for example, medical laboratory technology, nutrition, and dietetics. Those from natural science include, for example, plant science, fisheries, and biodiversity.

[7] Notably, articles that use the term "standards" in a broader meaning, i.e. "living standards," and "educational standards" have been filtered out. For the term "developing countries" and its alternatives, articles that use the term for the purpose of explaining backgrounds of certain global phenomena, but do not provide analysis that has obvious and significant implications to developing countries have been excluded. For example, a study on a financing mechanism for renewable energy technology mentions "developing countries" to explain sustainable development in its abstract, but does not look into the implication of the renewable energy technology in developing countries. In this case, the article was removed from the set for further review.

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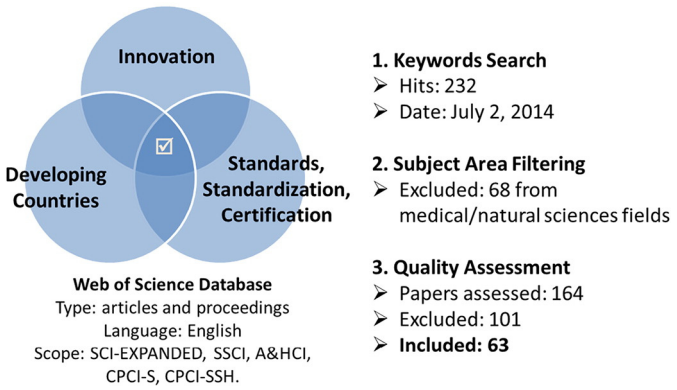

Fig. 1. Review areas and processes of systematic literature review.

have been excluded. The remaining 63 articles are finally selected for further analysis.

For the third part, reporting, we first present the descriptive statistics of the reviewed articles in Table 1. The classification of the literature and the conceptual model drawn from the synthesis of the findings are presented in the sections following. A review of 63 sampled articles confirms that the combination of innovation, standardization, and developing countries is indeed an interdisciplinary research topic. The result indicates that significant contributions have been made from business economics studies. A qualitative case study investigating innovation in developing countries at the industry and cluster level is the most common form. In geographical terms, China attracts the bulk of research attention followed by other BRICS countries.[8]

4. Findings

We categorize the literature to understand the dynamic roles standards and standardization play in the changing context of innovation in developing countries. For this purpose, we draw on Blind's (2013a) classification of the four types of standards and their effects on innovation. Building on his work, we discern three categories of research according to the main economic functions of standards addressed in the literature: variety reduction, minimum quality and safety, and compatibility and interface standards.[9] And we discuss how these standards have similar and sometimes different effects to innovation in the specific context of developing countries. We further expand his work by drawing out economic and social implications of the innovation-standardization dynamics in addressing the developmental challenges. Then, we take the results to draw a conceptual model of the conditions under which the innovation-standardization relationships stand out in the context of developing countries.

4.1. Variety reduction standards: innovation by scaling

In a traditional sense, standards set out a certain specification of a product such as the size or quality levels (Tassey, 2000, p. 590). These specifications limit or "optimize" the variety of a product, which means that a smaller number of inputs are required in the production process. By adopting variety reduction standards, manufacturers can reduce the production cost and increase the production volume to achieve economies of scale. Variety reduction standards affect innovation by allowing such an optimization of the production process. The exploitation of the economies of scale also helps the diffusion of new products as a type of innovation (Blind, 2013a).

In our sample literature, variety reduction standards are an important strategy of industrial capacity building and upgrading in the catch-up context as a catalyst to process optimization or "modernization". A notable example is the case of catch-up in South-African wine sector (Cusmano et al., 2010). The authors depict how wineries in developing countries were able to succeed in the global market against the stronghold of incumbent wineries in Europe. While the old world wineries stayed with a small-amount, large-variety production of high-end wines, the follower wineries went through a process of product modernization which focused on reducing the production cost while increasing the production capacity. In this change, product standardization played a key role in effectively decreasing the production cost by reducing the variety of products and eventually creating a new market for mass-produced, lower-priced wines.

In addition, variety reduction standards serve as a tool to disseminate the benefits of innovation in developing countries in a large scale. Scaling, which can be defined as "the expansion of the system in scope and size" (Braa et al., 2007, p. 384), presents an opportunity to replicate proven solutions to other similar environments and expand the scope of the impact of innovation. In this regard, Foster and Heeks (2013) show standards as a "scaling" mechanism of a locally driven innovation for the bottom of the pyramid (BoP) market. The standardization stage in the M-Pesa, a well-known mobile banking in Kenya, was an effort to reduce service varieties and drive down the operational cost so as to maintain an adequate level of service price for its consumers and to ultimately expand its service market. The authors also mention that standardization of the M-Pesa entailed an important process of institutionalization, aimed at expanding the outreach of the essential financial service as it constantly evolves by responding to local needs. In this view, variety reduction standards are not only a strategy to attain price competitiveness by tapping into the economies of scale, but a mechanism to achieve inclusive innovation by widening the access to innovation for a marginalized population.

In sum, variety reduction standards, by achieving reduction of production or service costs, facilitate innovation. Even though not clearly defined in many cases, innovation in this category is incremental changes aimed at achieving firm-level manufacturing or service efficiency. Impacts of the innovation-standardization dynamics are expected to be largely conducive to socioeconomic development.

4.2. Minimum quality and safety standards: innovation by proving

Innovation, with novelty in its nature, accompanies certain risks and uncertainty. As Swann (2010) mentions, standards are a tool to avoid undesirable outcomes of innovation that may arise from this uncertainty. In particular, minimum quality and safety standards, by setting requirements for properties of goods and services to assure a certain level of quality (de Vries, 1999), prohibit inferior goods and services from being offered by suppliers and circulated in the market (Blind, 2013b). With these measures, consumers have increased confidence in innovative products and services,

[8] A full table describing the characteristics of the sampled articles can be found in the Appendix A.

[9] We have omitted the information standards from Blind's (2013b) original categorization of four types of standards, due to the overlapping characteristics with the rest of standards as well as the mere scarcity of articles that purely address the mechanism and results of information standards and innovation. In addition, the classification of the three types of standards is not categorical. For example, there are articles that do not specifically describe the characteristics of standards or standardization that they address, making it difficult to classify them into a specific category. In these cases, for the purpose of this paper, we made decisions based on the topic areas and the industries the articles deal with; for example, an article is classified under the quality standards if it deals with agricultural producers in the GVC, while one addressing standardization in the ICT industry is classified under the compatibility standards.

Table 1
Descriptive statistics of sample articles.

Category	Proportion of sample articles	Category	Proportion of sample articles
Academic discipline	• Business economics (32%) • Information/computer sciences (22%) • Agriculture (12%) • Engineering/energy (11%) • Public administration/law (10%)	Level of analysis	• Industry or network level (37%) • National level (32%) • Firm level (19%)
Methodology	• Qualitative (52%) • Quantitative (36%) • Combination (7%) • Theoretical (5%)	Geographical region	• China (25%) • Multiple countries (24%)[a] • India (6%) • South Africa (5%)

[a] When an article includes multiple country cases, it was counted repeatedly.

which will facilitate the diffusion of innovation in the broader society.

In our sample, the link between the adoption of minimum quality and safety standards and innovation turns out to be a frequently researched topic. Its importance can be explained in three aspects. First, while the international quality and safety standards do not necessarily contain new-to-the-world innovation, they tend to involve significantly improved methods or skills in the production process that are new to the situation in developing countries. Given the relatively low stock of knowledge and unsatisfactory organizational, technological and managerial practices in developing countries, the relationship between international quality standards and innovation is expected to be strong (Freitas and Iizuka, 2012). Second, due to the global-scale externalities arising from the provision of global public goods (Unnevehr, 2007),[10] there has been a greater use of international quality and safety standards to harmonize different national regulations and to correct for the negative externalities including those from the developing countries as a "weak link." Last but not least, international quality and safety standards are a prevalent mechanism of vertical control in the global value chains (GVCs). Particularly in the agricultural sector as a key export industry in many developing countries, the attainment of international quality standards and certificates help producers signal their adherence to good practices to consumers and gain an access to export market in advanced economies for increased income (Peña-Vinces and Delgado-Márquez, 2013).

In terms of the impact on innovation, our analysis shows that the effects of quality and safety standards are nuanced. On the positive side, the adoption of minimum quality and safety standards is in itself a type of process innovation, by allowing what Srinivas (2012) calls "learning by proving" for firms in developing countries. As a requirement to export to markets in advanced economies, firms in developing countries need to "prove" that their products and services adhere to certain quality standards that respect the health, safety, or environmental priorities of the importing countries such as GLOBALG.A.P. and HACCP (Schipmann and Qaim, 2010), and international management standards such as ISO 9001 and ISO14001 (Correa et al., 2010). In their efforts to achieve compliance to these standards, firms in developing countries improve their productivity and innovate by repeating the "proving" process (Kadarusman and Nadvi, 2013). Here, the governance structure of the GVC, which indicates how firms in developing countries as suppliers in the GVC form a relationship with the lead firm in the chain, significantly affects the extent to which supplier firms can gain innovation capability (Gereffi et al., 2005). Lead firms, usually as a creative core in the chain, serve as an important source of external knowledge for innovation, while at the same time exert "pressure to learn" to firms in developing countries for conformance and control.

In addition, Srinivas' (2006) research examines how standardization as a procurement mechanism facilitates quality upgrading. She takes note that Indian vaccine firms were able to improve product quality and innovate as they strive to meet quality standards as a requirement to respond to the global procurement opportunities offered by international health initiatives. The Indian government and international organizations, by developing and referencing standards in the procurement, spelled out specifications and requirements of the products concerned, expressing the distinct demand of the buyers. These standards in turn served as a key guideline for Indian pharmaceutical firms to upgrade their innovation capability. Such a use of standardization as a procurement mechanism has been also noted by Blind (2013b) as an important industrialization policy. Standards can be referenced in the public procurement not only to increase the efficiency of the procurement process but also to promote demand-driven innovation in the industry.

However, on the negative side, a stream of research reports the adverse effects of quality and safety standards on innovation. First, it is argued that there is very weak "diffusion" of innovation due to the institutional weaknesses in developing countries. For example, Tong et al. (2012) point out that the proliferation of international environmental standards and the global regulatory harmonization may result in dual regulatory systems in developing countries: one for the lower-regulating domestic market, and the other for stricter overseas markets. As a result, local consumers may not enjoy the same level of protection for global public goods—indicating that innovation does not necessarily have a spillover effect to the domestic population. Second, the top-down requirement of "innovation by proving" exemplified in the GVC and global regulatory harmonization may exclude smaller firms and producers in developing countries from the global market. While their adoption is deemed an important qualification for a specific market, the standards may serve as an entry barrier to those with less financial and institutional resources when the cost of compliance is too high (Preißel et al., 2010). In this sense, even though institutional innovation such as SPS Agreement may have mitigated disputes related to food safety by adopting international standards, in fact such innovation may restrict competition and even reduce trade.

4.3. Compatibility and interface standards: innovation by coordinating

With the advancement of Information and Communication Technologies (ICTs), the importance of compatibility and interface standards has also increased significantly. These standards concern

[10] Global public goods are characterized by benefits and externalities on a global scale (Unnevehr, 2007). For example, environmental sustainability is traditionally considered a global public good. Unnevehr (2007) notes that food safety has become a new type of global public good with the expansion of the global agro-food sector and integration of the supply chain.

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the "fitting of interrelated entities to one another in order to enable them to function together (de Vries, 1999)". The physical and functional interoperability secured by the compatibility and interoperability standards lays a foundation for achieving network effects, which refer to "the additional value that arises from the usage of a product or service by an installed base of users" (Techatassanasoontorn and Kauffman, 2014). In the innovation process, compatibility and interface standards are a crucial element for the development of the industry, as they ensure seamless connection between related products and facilitate diffusion of the innovative products.

Our analysis shows that compatibility standards in developing countries are also inseparable from the realization of network externalities, under two conditions.

First, given the relatively expensive cost of building and maintaining infrastructure in developing countries, the network effect is expected to play a more important role in innovation diffusion in developing countries (Friebe et al., 2014; Rouvinen, 2006; Techatassanasoontorn and Kauffman, 2014). In particular, examples of compatibility standards in health information systems show this aspect. Braa et al. (2007) illustrate how carefully developed data compatibility standards can help overcome the heterogeneity of infrastructure and capabilities in the development of national health information systems. Information systems development in developing countries tends to suffer from an absence of architectural blueprints and central coordination. This often results in incompatibility of different information systems in key public service areas, which significantly limits the overall impact of the ICT innovation. Braa et al. (2007) emphasize that the development of simple, flexible compatibility standards can solve the problem of system fragmentation. Compatibility standards, as a main "attractor," ensure a minimum level of interoperability for as many systems as possible, so as to tap into a maximum level of network effects and to magnify the impact of the ICT innovation in the health sector. Considering the ever-growing donor investment for the ICT integration in key areas of public service such as health, social security, and education in developing countries (Avgerou, 2010), appropriate development and use of compatibility standards, by allowing a seamless operation of different systems and services, generally contributes to development.

Second, a stream of literature displays how some developing countries as a technology frontier use compatibility standards development as a strategic tool to coordinate innovation in key industries. Particularly, the topic of the third generation (3G) telecommunication standardization in China is a frequently studied example, showing how a leading actor, the government, uses standards to spur and disseminate indigenous innovation in response to the intensifying competition in the global ICT industry (Gao et al., 2014; Gao, 2014; Kshetri et al., 2011; Vialle et al., 2012; Yu, 2006).[11] Through various incentive and regulatory policies, the Chinese government led the standardization drive, which involved building an entire eco-system of the indigenous technology including the establishment of domestic installed base and the development of international standards (Vialle et al., 2012). In this process, compatibility standards coordinated different components and systems to increase the scope of impact of the innovation. As some contemporary scholars argue, standards successfully served the government meeting its own political agenda; that of achieving a technological independence and increasing the national pride by "waging a standardization war" (Lee and Oh, 2006; Suttmeier et al., 2006).

However, some authors question the true technological and societal merit and impact of such an innovation by "coordinating" (Gao, 2007; Gao et al., 2014). For example, Gao et al. (2014) criticize that in spite of the size of the Chinese market and the strong governmental influence over the telecommunications industry, the market acceptance of TD-SCDMA in commercial terms was limited. In addition, this case also hints at the potential negative effects of compatibility standards that may restrict competition and lead to monopoly, considering the fact that there was a strong political push by the Chinese government to disseminate indigenous innovation by openly favoring Chinese domestic firms over foreign firms.

By and large, compatibility standards are an important tool to facilitate innovation in the ever-important ICT industry, given the domestic resource constraints and the augmenting international competition. Innovation tends to be indigenously oriented; some are new to the world, while others entail re-engineering of existing technologies. The interplay between innovation and standardization is perceived highly embedded in the local context, reflecting the economic, social, and political priorities and constraints in the developing countries concerned.

4.4. Summary of findings

Table 2 summarizes the findings from the categorization of the literature, in terms of the dominant context of the interplay between innovation and standardization, characteristics of innovation that appear in the relationship, impacts of standardization on development, as well as the main agents involved and the industries concerned in the literature. Building on these findings, we synthesize a conceptual model of innovation and standardization in developing countries in the next section.

5. Discussion

The purpose of this section is to draw a conceptual model of the relationship between innovation and standardization in developing countries (Fig. 2). We reflect on findings from the categorization of the literature to figure out the overall boundary of the context and goals, characteristics of innovation and standards/standardization, and the impacts of the relationship between innovation and standardization that are relevant in developing countries. We also discuss in detail some of the overarching elements from the categorization, the roles and relations of key actors and the inducing or blocking mechanisms.

5.1. Context and goals

Regarding the context of the innovation-standardization link in developing countries, two attributes stand out in the extant literature. First, the current literature emphasizes that the global integration of the economy and the intensifying competition set out the external conditions developing countries face. Developing countries are requested to increase their global market competitiveness by strengthening the production and innovation capabilities, as well as to raise the level of compliance with international regulations concerning trade and environmental sustainability. Given these economic and regulatory pressures from the outside, developing countries need to find strategies to fulfill these calls. On the other hand, the domestic conditions in the developing countries are mainly addressed under the framework of NIS. Even though the conditions determining the specific institutional attributes of a given country differ from one country to the next, certain shared assumptions exist, notably marked by resource deprivation and inadequate institutional coordination. These attributes pose another imperative to spur the innovation-standardization relationship in the developing countries.

[11] As typically in other mobile communication standards, TD-SCDMA standards entail a variety of contents and types of standards that are not technically classified as compatibility or interface standards. However, for the purpose of our analysis based on the four types of standards, we classify those 3G international standards related to TD-SCDMA technology under the compatibility standards, counting on the key characteristics of the standards that enable compatibility of different components and products within a single system.

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In terms of the goals and impacts of the relationship, the innovation-standardization link serves economic objectives by allowing temporary monopoly rent in the market, social objectives by "identifying more effective solutions that add value for the people affected by development challenges" (UNDP, n.d.), and to a lesser degree, political objectives by fulfilling the government's agenda for global competition.

5.2. Characteristics of standards/standardization

We observe that the focus of current literature is skewed toward the adoption aspect of standards, rather than the development of standards.

In fact, the question of why firms join standardization as an innovation strategy in the upstream is already an important research topic in the extant literature featuring some industrialized countries (Wakke et al., 2015). However, there is a limited number of research that investigates this dimension in our sample of reviewed literature, possibly due to the lack of actual cases of strategic standardization in developing countries except for a few examples from South Korea and China (Choung et al., 2012). The methods of standards development are also limited to the *de jure* standardization, and less attention is paid to other modes of standardization such as *de facto* standardization and private standardization fora (Gagliardi, 2015). This result also resonates with the scant academic attention to the networking opportunities standardization offers as a channel of knowledge sharing and coalition building. Networking is one of the important indirect benefits of joining standardization, which helps firms gather valuable anticipatory and insider information available among participants, and build strategic coalition as an important source of innovation (Blind, 2013a; Wakke et al., 2015). However, currently, such an aspect of standardization as a networking avenue for innovation is not well-researched yet in the context of developing countries. Even though the government-led partnership building is addressed particularly in the case of Chinese telecommunication standardization, the analysis is limited to the role of the government in partnership coalition rather than the dynamic interactions among stakeholders based on their strategic judgments and choices.

5.3. Characteristics of innovation

In terms of the characteristics of innovation shaped in the interplay with standardization, we observe clearly different scopes and foci between literatures on developed and developing countries. In general, the incremental, new-to-the-situation innovation takes the main share, for which foreign-born international standards are the most frequently addressed knowledge source. Innovation of such characteristics is not usually measured as a formal "innovation" in a traditional sense, where innovation is usually frontier by nature based on original R&D efforts. Regarding the scope of innovation, firm-level innovation is found to be the most frequent. In cases where industry-wide or national innovation is discussed, it is the downstream relationship of distribution and adoption, rather than the upstream relationship of development of standards, that occupies the core part of analysis. Last but not least, innovation is not necessarily confined to the "technical"; in many cases, innovation happened simultaneously with the process of obtaining the public support critical for the dissemination of innovation, in line with what researchers call the "non-technical" innovation. As Gao (2007) notes, this indicates the co-evolution of physical and social technology, meaning that the adoption of scientific knowledge accompanies the coordination with the public stakeholders, especially the research community, to ensure its broader market acceptance.

5.4. Innovation-standardization relationship

Based on the discussion from the previous section, we return to the question of how the relationship between innovation and standards/standardization appears differently in the context of developing countries compared to the extant literature based on the advanced economies. Under the context of advanced economies, it is a generally accepted understanding that standards "stabilize" and thus "stagnate" technological development which serves as a source of the paradoxical relationship with innovation. Indeed, standards, purely in terms of the novelty of the technological contents concerned, may not represent the innovation frontier. However, it is the standards' positive effects on the market and regulatory aspects of innovation that offset the conventional negative connotation. For example, standardization, conducted at the right timing in the technological development, helps reduce the time to market for innovative technology and products. From the regulatory and coordination aspect, standards facilitate the emergence and dissemination of innovation by reducing the transaction costs.

Table 2
Economic and social impacts of standards on innovation in developing countries
Based on Blind (2013b) and OECD (2012).

Type of standard	Contexts	Type/source of innovation	Economic effects on innovation	Impacts on development	Main agents involved	Scope (industries)	Exemplar papers
Variety reduction	Catch-up, industrial modernization, building up niche competencies	Incremental based on adaptation of foreign innovation and/or local R&D; Innovation by scaling	(+) Economies of scale (−) Reduced choice	(+) Dissemination of innovation on a large scale (+) Inclusive innovation (+) Social technology (−) Neglect on local needs	Firms, universities and R&D institutes	Firm/industry (manufacturing)	Cusmano et al. (2010), Foster and Heeks (2013)
Minimum quality & safety	WTO, Global value chain (GVC), global regulatory harmonization	Incremental based on absorption of foreign innovation; Innovation by proving	(+) Reduced transaction costs (+) Correction for negative externalities (+) Facilitation of trade (−) Restriction of competition	(+) Capability upgrading (+) Spillover (−) Exclusion of weaker actors (−) Lack of legitimacy in the rule making	GVC lead firms/supplier firms	Supply chain (agro-food)	Perez-Aleman (2010), Kadarusman and Nadvi, (2013), Schipmann and Qaim (2010), Amekawa (2009), Tong et al. (2012), Hermann (2009)
Compatibility & interface	Resource-poor situation, national innovation system, global competition	Incremental/radical based on adaptation of foreign technology and/or necessity of situation/local R&D; Innovation by coordinating	(+) Network externalities (−) Monopoly	(+) Technical independence (+) Service delivery and problem-solving mechanism (−) Political capture	Government	Industry, sector (ICT)	Gao et al. (2014), Kshetri et al. (2011), Vialle et al. (2012), Braa et al. (2007)

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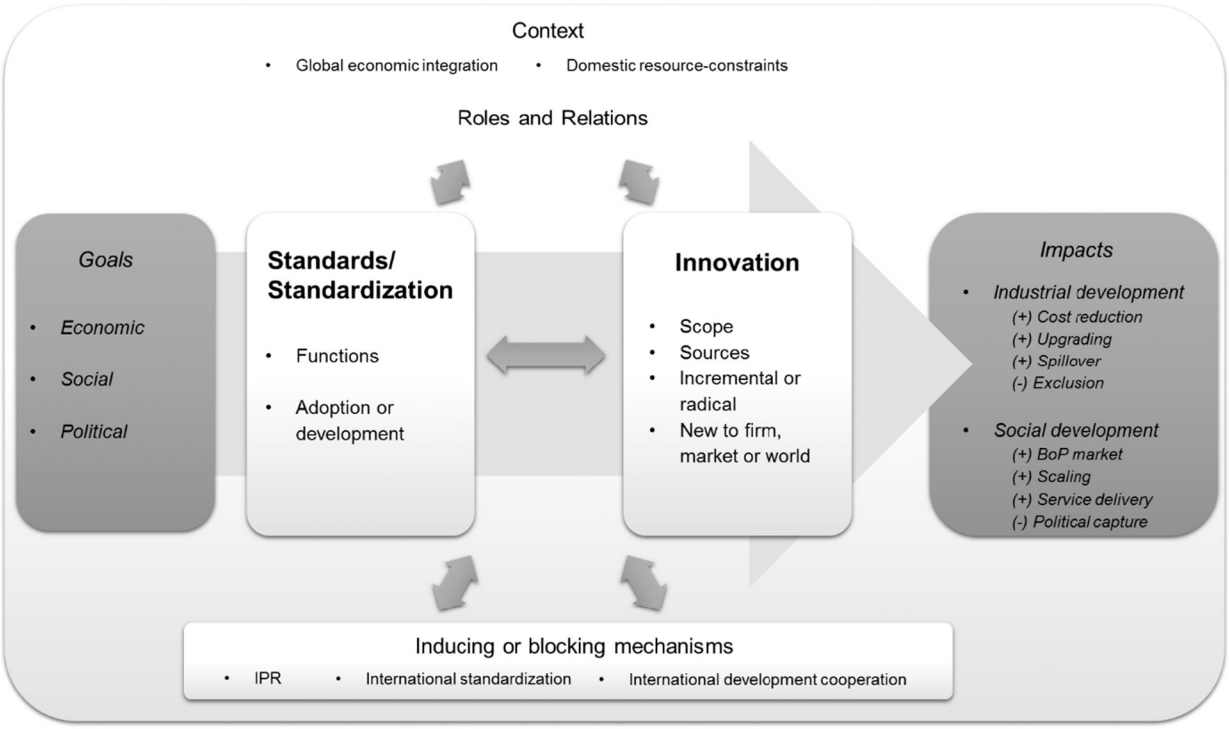

Fig. 2. A conceptual model of innovation and standardization in developing countries.

However, this observation on the source of the paradox appears differently in developing countries. As discussed, standards in developing countries in many cases indicate international standards, which already entail the nuance of novelty and excellence within them as an encapsulation of technical knowledge from the advanced economies. In this sense, at least from the technological perspective, the relationship between standards/standardization and innovation is not contradictory; the "change-inducing," and thus innovation-inducing characteristics are already implicated in the adoption of international standards in developing countries. Conversely, what is more at odds in the innovation-standardization relationship arises from the market and regulatory aspects. In the regulatory perspective, when the cost of trust building is too high due to the fees associated with acquiring standards and certificates, the incentives for innovation also reduce, with smallholder manufacturers and producers being the first to be excluded from the benefits of innovation. This aspect is also related to the diffusion of innovation in the market. When the cost of standardization and certification is too high, producers target for a market where it is more likely to return their cost. As a result, as seen in the example of the Indian pharmaceutical industry (Srinivas, 2006), it is usually the export market for the advanced economies where the newly acquired innovative capabilities are targeted, while the diffusion and generation of innovation in the domestic market is constrained or neglected.

In short, the "paradox" in the relationship between innovation and standards/standardization appears differently in the context of developing countries. It is not the "technology-freezing" characteristics of standardization; on the contrary, standards/standardization may strengthen the technological capabilities of key actors and facilitate the technological innovation in developing countries. Rather, tension arises when the benefits of innovation do not necessarily percolate through the domestic market and regulatory spheres, and when the market proliferation of standards/standardization generates negative side effects that may outweigh standards' contribution to the socioeconomic development in developing countries.

5.5. Roles and relations

Here, we discuss the different actors and their roles in the innovation-standardization dynamics in developing countries (Table 3). The inadequate levels of resources and capabilities in the innovation system in developing countries make it particularly important to involve various stakeholders and encourage different types of collaboration among them. While interactions among all the stakeholders are deemed necessary, the roles of the government and technology/industry support organizations are highlighted, as they complement the relatively weak technological capabilities of other actors in the NIS.

5.5.1. Government

Generally speaking, the government serves as an independent regulator that coordinates the technology suppliers such as firms and R&D institutes, and the users on the demand side. The government adopts standards as technical regulations to facilitate the diffusion of innovation (Brown and Thompson, 2011) and to provide necessary protection for consumers in the market against potential risks that may arise from the new technology (Gao and Rafiq, 2009). However, relatively weaker innovation and standardization capacities in developing countries in terms of the financial, institutional, and human resources tend to assign a pervasive role to the government (Dube et al., 2012; Gao et al., 2014).

Above all, the government directly engages in the technology supply. In the absence of independent resources and capabilities of individual firms to initiate long-term R&D and standardization projects, the government promotes technology development and diffusion by directly conducting or investing in research and standardization (Gao et al., 2014, p. 201). In addition, the government serves as a coordinator and facilitator of standardization. The tasks include actively pulling out the diverse interests of national stakeholders to shape the direction of technical development and improve the relevance and technical quality of the national standards. Even though exemplar cases are rare, researchers pay

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Table 3
Roles and relations of key actors in the innovation-standardization dynamics
Based on Gao et al. (2014).

Actors	Roles	Relations	Conditions
Government	Regulator Technology supply: investor, coordinator, implementer Technology demand: procurer	In a stronger role, forms and leads encompassing relationships with national actors for national innovation initiatives In a smaller role, serves as a coordinator for market-led initiatives	Executive power required Political, economic leverage required in international standardization for a stronger role
Firms	Adopters of foreign innovation	Maintain a close relationship with the GVC lead firm	Degree of agency depends on the GVC governance structure
	Innovators	Independently form alliances outside the original GVC	For success, strong internal R&D capability required
R&D institutes	Supporters of technology development Providers of basic research for innovation	Participate in national initiatives led by the government or in few cases, firms	For success, strong R&D capability and collaboration networks with global scientific/research community required
Business/producer associations	Intermediary for the diffusion of standards/innovation: adopters of foreign innovation, trainers, (self) regulators	Maintain a close relationship with firms, producers, and international practice	Fair representation of stakeholders necessary
MSTQ	Intermediary of the diffusion of standards/innovation: trainer	Maintains a close relationship with firms, producers, and international practice	Relatively weak in the standards development function
Consumers	Users of technology	Currently don't have strong relationships/networks with other actors	Growing representation in innovation/standardization process required

attention to the state-led standardization initiatives in developing countries that promote participation and coalition of private sector participants for indigenous innovation. By providing adequate incentives, the government establishes partnerships, both domestic and external, to strengthen the local scientific and technological capabilities (Gao, 2014; Kshetri et al., 2011). In addition, to a lesser degree, the government involves in the technology demand by utilizing standardization as a procurement strategy and inducing relevant innovation for the unmet local needs. In some cases, the technological demands are shaped with a strong political intention, as the developing country government aims to expand its technological influence in the global market.

In another note, there are certain benefits of a smaller role of the government in the standardization-innovation dynamics (Bekker et al., 2008). In this line of research that values the market approach vis-à-vis one led by the government, it is argued that the "small government" provides a greater room for private actors to collaborate and innovate, thereby contributing to the national economic development even more. In addition, considering the relatively weaker institutional strength in the government sector in developing countries, this may effectively prevent the risks of coordination problems arising from the fragmented government agencies. In this context, the capabilities of a broad set of stakeholders outside the national government become more important.

5.5.2. Private actors—firms, R&D institutes, and associations

A firm is traditionally one of the leading actors in the supply of technological innovation and standards. Yet, firms in developing countries do not receive the same amount of attention as a leading actor of the innovation-standardization dynamics due to their general lack of resources and capabilities. Frequently, they are depicted as supplier firms under the GVC, passive adopters of standards whose innovation capabilities are prescribed by the governance structure of the GVC. In addition, considering that standardization mainly serves as a distribution mechanism of innovation rather than an inducement mechanism, the strategic emphasis is placed on the absorptive capabilities, as opposed to the innovation capabilities of firms. In fact, a small number of cases exist where a supplier firm with sufficient managerial and technical expertise facilitates the standardization efforts as a part of a domestic innovation project (Cusmano et al., 2010; Gao, 2014; Kadarusman and Nadvi, 2013). However, it is difficult to generalize the results, since the success cases assume a strong R&D capability of a firm, combined with the unique political context characterized by either intentional or unintentional absence of the government intervention.

Another important actor in the technology supply is the R&D institutes and university-based researchers. In developing countries, the relatively weak R&D capabilities of these institutes have made research-based innovation and standardization difficult to achieve. A small number of research exist that illustrates how independent domestic research capacity allowed to build the overall architecture of a national innovation project and localize international standards suitable for effective performance in the local technological context (Bekker et al., 2008; Cusmano et al., 2010). In addition to the knowledge aspect, participation of R&D institutes in the national innovation project augments the political legitimacy of the project prioritization, as their participation signals a clear prospect of achievement based on scientific knowledge. Last but not least, their links with private firms are weak except for a few cases (Cusmano et al., 2010); it is usually the government who strategically brokers and forms an innovation network with R&D institutes and firms.

In the absence of competency of the traditional technology suppliers, business associations and technological support organizations, as an intermediary between technology supply and demand, play a substantial role. First, the business and producers' associations reduce the diffusion gap on the firm and producer's side. For example, Freitas and Iizuka (2012) describe the importance of the "repackaging processes of knowledge and information" carried out by business associations, as they provide support for local firms to adequately interpret and apply international management standards. This result is also supported by Perez-Aleman (2012); while the exposure to innovation technology at the individual firm level does not necessarily increase the actual adoption, exposure at the collective level, particularly through producer and industry associations, is more likely to increase the technology adoption. These findings resonate with Farrell and Saloner's (1985) argument that in the market with incomplete information, the excess inertia, which refers to the reluctance to move to newer and better standards due to the coordination cost involved in the incumbent technology, always happens. While some or all firms may have interests in the new technology, they are "insufficiently" motivated to adopt it, leading to a status quo (Farrell and Saloner, 1985, p. 71). Thus, in developing countries where information asymmetry tends to be higher, the role of business associations as a communication channel to alleviate the coordination problem becomes even more important in the adoption of innovation.

Second, the competence of technological support organizations, namely the metrology, standardization, testing, quality assurance,

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accreditation and certification (MSTQ) is important (Pietrobelli and Rabellotti, 2011). Currently, their role is more significantly pronounced in the distribution dimension. Compared to the R&D institutes which usually serve as the core of physical technology development, the MSTQ institutes can be understood as the center of the "social technology", which refers to the tasks of distribution and coordination that go along with the evolvement of physical technology. In the absence of the pure innovation capability to guarantee the technological merit of innovation, standards serve a critical role in the innovation process in developing countries by bringing about the social consensus on the relevance and value of the innovation. Such "non-technical capabilities" for innovation comprise a key condition to successfully generate innovation in developing countries. Therefore, the extension services such as training and consulting provided at the MSTQ institutes are key instruments of innovation diffusion, as they reduce the complexity of transaction involved in the use of new standards.

Next, consumers in developing countries in the demand side of technology are a significant, but under-researched key actor in the innovation-standardization dynamics. While the traditional characterization of consumers in developing countries as possessing a weak purchasing power rendered them negligible as a potential market, the growth of economy in developing countries, combined with the growing recognition of BoP as a frontier market, lends an added importance to the role of consumers in the innovation and standardization dynamics.

Last but not least, the strategic partnerships and support networks among stakeholders are considered an important ingredient of success in order to compensate for various constraints of both market and institutional nature (Soh and Yu, 2010). As mentioned, realizing the benefits of innovation not only requires technological expertise, but also a competency over the process of commercialization and market delivery. These include the institutional arrangements from the government side such as regulations, licenses, or subsidies, as well as marketing advantages from leading firms. Strategic partnerships allow actors to have a control over the assets they do not themselves possess for the delivery of innovation.

5.6. Inducing or blocking mechanisms

There are many internal and external factors that may facilitate or hinder the innovation-standardization dynamics.

5.6.1. IPR

First, we focus on the global regime of intellectual property rights (IPR). One of the key motivations of standards development is the reduction in foreign dependence (Kshetri et al., 2011), which is an economic imperative for developing countries in the face of deepening dependency on foreign technologies. The cost of technology is inherently linked to the highly debated issue of intellectual property rights (IPR) in developing countries.[12] In the context of WTO Agreement on Trade-Related Intellectual Property Rights (TRIPs), developing countries are required to strengthen their national intellectual property (IP) regimes. Developing countries tend to be net importers of technologies in high-tech industries, and they have to pay royalties to foreign companies for IP contained in the standards.[13] In this sense, indigenous standards development would provide an opportunity to reduce the outward flow of royalties by replacing the foreign standards, or even reverse the flow by exporting indigenous standards (Kshetri et al., 2011). This will in turn contribute to domestic market development and the national economic growth.

In this regard, a case in point is the TD-SCDMA standardization in China. The Chinese government strategically supported the TD-SCDMA standardization with an aim to break such a dependency of domestic manufacturing sectors on foreign technologies, which resulted in systematic support for the state-owned companies to own the core intellectual property rights of TD-SCDMA (Gao et al., 2014). In addition, this case also shows how the Chinese government used IPR transfer as an incentive mechanism to attract participation of key stakeholders in the wagon of indigenous innovation. Recognizing that commercial entities play critical roles in shaping standards in the ICT industries, the government ensured a certain level of protection of the interests of private parties who had made investments in intellectual property surrounding the TD-SCDMA development. Such actions are in line with the argument that innovation rent should be protected more when the availability of skilled workers is low (Acemoglu et al., 2012, p. 593). IPR protection measures of the Chinese government helped key stakeholders including foreign firms with core technical capabilities expect potential profit from the innovation and eventually join the development of TD-SCDMA standards.

On another note, the relatively weak IPR protection in developing countries is mentioned as a major hurdle to encouraging innovation, as it undermines the incentives of innovator firms to pursue high monopoly rent which would compensate for the investment required in the innovation (Acemoglu et al., 2012). In this perspective, Srinivas' (2006) research provides an interesting example. The weak IPR control based on the process patent in India, during the leapfrogging of the Indian vaccine industry, allowed Indian vaccine firms to gain access to knowledge stock essential for innovation. The ensuing innovation in the Indian vaccine industry helped to a certain degree improve the access to medicine in India by reducing the cost. However, it did not necessarily promote pharmaceutical innovation that responds to the local needs. The innovation-standardization dynamic failed to capture the needs of "local buyers" such as the demand for drugs for "neglected diseases" (Hassan et al., 2010), while the production capacity of the industry was geared towards meeting the "global" needs with incomparably greater market opportunity. The innovation efforts failed to withstand the low incentive problem posed by the weak domestic IPR regime.

5.6.2. International standardization mechanism

Second, the governance mechanism of international standardization also functions as an inducing or blocking mechanism of the innovation-standardization link. Considering that the international standardization arena usually serves as a forefront of technological innovation where various actors ranging from firms, scientific and educational institutes, regulators to civil society gather for competition and coordination, access to international standardization

[12] The argument behind strengthening IPR regime in developing countries is the belief that a strong IP protection would generate additional benefits to developing countries leading to more R&D and innovation, which would in turn facilitate economic growth (Hassan et al., 2010). However, critics argue that IP is not perceived as an opportunity structure and incentives for innovation in developing countries. Rather, the price of products and services that include IPR protected technology tend to be higher due to the royalty payments, thus making it unaffordable for consumers in developing countries. They suggest that the relatively high norms of IP protection in the current governance system under the Trade-Related Intellectual Property Rights (TRIPS) only serve the rents of past and present innovation which largely originate from the advanced industrialized countries. Some also question the legitimacy of the process of international IP standards setting surrounding the TRIPS, arguing that developing countries were not able to influence the bargaining process due to the limited representation and access to full information, and the dominance of strong players (Drahos, 2002). The resulting universal high norms of IP protection lead to limited affordability of innovation products and services in developing countries, which then results into a significant limitation to the future innovation opportunities (Reichman, 2007).

[13] In general, standards and IP are considered to be in conflict with each other; as Shin et al. (2015) note, "a standard is a tool for diffusing innovation", while "IP is a tool for securing innovation" by controlling its use. In this sense, standardization and the use of standards may complement the current IPR regime to better disseminate innovation, which may sometimes hamper the diffusion process due to excessive protection of the intellectual properties contained within innovation. One such intersection between standards and IPR occurs when a standard contains IPR-protected contents, for example as in "standard-essential patents (SEPs)." SEPs refer to patents that have to be infringed when implementing a standard because there are no commercially and technically feasible non-infringing alternatives (CEN-CENELEC, 2016). In this case, the patent holders should negotiate for licensing under fair, reasonable and non-discriminatory (FRAND) terms and conditions. However, difficulties arise when the patent owners refuse to provide license, or require too high licensing fees.

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significantly improves the innovation capacity of the country. Notably, Choung et al. (2012) emphasize the importance of national standards capability in a country's innovation strategy, and argue that participation in formal standardization is an important avenue of obtaining standards capabilities. However, in general, developing countries face constraints of technical, organizational and financial nature in participation in international standardization processes, leading to a lack of representation of actors from developing countries in major international standards development organizations. Some studies even challenge the legitimacy of the international standards as a *de facto* global regulatory mechanism, and raises a concern of potential regulatory capture (Blind, 2013b). For instance, Schut et al. (2014) point out that the lack of representation of developing country actors in the SPS standards leads to unnecessary upward trends of technology used in the international standards, which further consolidates the exclusion. Hermann (2009) also argues that the current system of international standardization and certificates fails to provide adequate solutions for indigenous industries such as novel food and traditional medicines.

5.6.3. International development cooperation

Even though the numbers are small, the extant literature addresses international development cooperation as an important factor that either facilitates or hinders the interplay between innovation-standardization in developing countries. For example, Srinivas' (2006) analysis of the innovation in Indian vaccine industry reveals how the procurement decisions of the international agencies such as the World Health Organization (WHO) and United Nations Children's Fund (UNICEF) to give priorities to the suppliers from developing countries have opened a window of opportunity for Indian vaccine companies. As mentioned earlier, the quality standards set out by these international procurers helped local vaccine firms in India upgrade their quality and gain international market access. Even though the positive effects have not been pervasive and the firms ultimately fell short of meeting the expectations of the local healthcare needs, the opportunity certainly provided an "important industrial and technological turning point (Srinivas, 2006, p. 1747)." In this sense, the mechanism of international development cooperation facilitates the innovation-standardization dynamics in developing countries, a point for which further research efforts are needed.

5.7. Impacts

Currently, the impact of the innovation-standardization relationship is largely concentrated on industrial development. Most of the literature assumes economic growth, including industrial capacity and firm-level competitiveness building as a prominent goal of the innovation-standardization nexus. Yet, research on the distributional effects of the relationship, such as access to public services, sustainable livelihoods, and alleviation of rural poverty is relatively scant.

Taken together, this finding implies that there is a conceptual distance between the foci of current literature and the socioeconomic development in developing countries. As Dube et al. (2012) express, there exists an assumption of "virtuous spiral" that the economic benefits gained from the positive relationship between innovation and standardization would naturally enhance the social development. However, as seen in the analysis, not all standardization-innovation dynamics fulfill the developmental potentials. In this sense, there is a need for a new research agenda that examines how the interplay between standardization and innovation can facilitate the delivery of key public services to address the unmet social demands in developing countries.

6. Conclusion

This paper shows that in the current body of academic literature, the interplay of innovation and standardization in developing countries appears in multiple ways, revealing the economic as well as the broader social dimensions of the relationship. It contributes to expanding this emerging, interdisciplinary research frontier and identifying research gaps. From the perspective of development studies, further analysis on the interplay of innovation and standardization can be conducted to deepen the understanding on the capabilities of development (Chaminade et al., 2009). From the practice side, standardization can be a valuable instrument to scale up innovative pilots into a large scale deployment or to induce innovation as a solution to development targets. From the perspective of innovation and standardization studies, further research on the context of developing countries may shed light on the match and mismatch between innovation and market, and on whether and how innovation and standardization should embrace the emerging societal needs. As Blind (2013b) states, innovation is not only the engine of a country's competitiveness and growth in an economic sense; it is also "the key to solve big challenges for today's societies like climate change, scarcity of natural resources, (…), health and security".

With the recent endorsement of United Nations' Sustainable Development Goals (SDGs) as a new global direction for development cooperation (United Nations, 2015), a growing attention is given to the roles of innovation and standardization in alleviating poverty and addressing technological and social challenges in developing countries.[14] Does the increasing visibility of these international efforts resonate with the findings of the current research? The burgeoning attention paid to the interplay of innovation and standardization in development cooperation practice does call for increased academic interests and efforts in this topic. Most significantly, the small amount of current literature on this topic attests the lack of open, common theoretical grounds upon which further empirical evidence can be collected. With continuing attention from scholars of broad academic backgrounds, the topic can become a meaningful field of study for academia as well as practice particularly in the domain of standardization and innovation studies on the one hand, and in the domain of development studies on the other.

Last but not least, we find the following research gaps for future studies. First of all, in most of the current literature, the notion of what development means, and how innovation and standardization can facilitate it, is either assumed implicitly or underemphasized. Considering the chasm between the industrial and societal goals of innovation revealed in this paper, future research on this topic may contribute to bridging the gap. In addition, more theoretical studies are required in order to further explore the synergetic potential of innovation and standardization in developing countries and to develop new research frontiers. As mentioned earlier, current literature mostly focuses on what de Vries (2015) calls the 'acceptance' and 'use' aspects of standards, as to how standards are accepted in developing countries within the global environment. To make a balance, research on specific standards or the development of standards in developing countries is needed. With regard to research approaches, individual-level or community-level studies focusing on smallholder farmers or micro-/small-sized entrepreneurs may shed light on the actual distributional effects of innovation and standardization in developing countries. Finally, in terms of the geographical coverage, more research is needed from regions beyond those major emerging economies such as China, India, Brazil, and South Africa.

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[14] Notably, among 17 goals of SDGs, goal 9, Industry, innovation, and infrastructure directly addresses the importance of innovation for development. In addition, technical assistance for international standards as a key measure to ensure seamless global trade have been an important part of the *aid for trade*, which refers to the development assistance dedicated to support developing countries' access to global markets by helping countries articulate, communicate and mainstream their trade-related objectives (OECD/WTO, 2016). SDG goal 8, decent work and economic growth includes the *aid for trade* as one of its targets.

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Appendix A. Data sources of research on innovation and standardization in developing countries.

	Paper	Unit of analysis	Sector/topic area	Methods	Data used
1	Gao, XD (2014)	Firm	ICT	Qualitative	Archival data, interviews
2	Koenig-Archibugi, M; Macdonald, K (2013)	Country	Labor	Qualitative	Archival data, interviews
3	Pena-Vinces, JC; Delgado-Marquez, BL (2013)	Firm	Manufacturing	Quantitative	A survey of 100 Peruvian exporting firms
4	Dean, JM; Lovely, ME; Wang, H (2009)	Firm	Environment	Quantitative	Authors' dataset of 2886 manufacturing equity joint venture (EJV) projects in China
5	Alkraiji, A; Jackson, T; Murray, I (2013)	Industry	Health, ICT	Qualitative	Archival data, interviews of 33 participants
6	Cusmano, L; Morrison, A; Rabellotti, R (2010)	Industry/network	Agri-food	Qualitative	Archival data, interviews
7	Bhattacharya, S; Shilpa; Bhati, M (2012)	Country	Nanotechnology	Mixed	Secondary data from citation and patent database (SCI-E, Thompson Innovation Patents database, USPTO)
8	Kshetri, N; Palvia, P; Dai, H (2011)	Industry/network	ICT	Qualitative	Archival data, interviews
9	Vialle, P; Song, JJ; Zhang, J (2012)	Industry/network	ICT	Qualitative	Archival data, interviews
10	Kadarusman, Y; Nadvi, K (2013)	Industry/network	Garment	Qualitative	Secondary data, interviews, a survey of 22 garment firms and 15 electronics firms in Indonesia
11	Hilson, G(2014)	Industry/network	Mineral	Qualitative	Archival data, interviews
12	Gao, P (2007)	Industry/network	ICT	Qualitative	Archival data, interviews
13	Herzfeld, T; Drescher, LS; Grebitus, C (2011)	Country	Agri-food	Quantitative	Secondary data from BRC Food Technical Standard and GlobalGAP certificate data (2007)
14	Braa, J; Hanseth, O; Heywood, A; Mohammed, W; Shaw, V (2007)	Industry/network	ICT	Qualitative	Archival data, interviews
15	Rouvinen, P (2006)	Country	ICT	Quantitative	Secondary data from EMC's World Cellular Database, ITU, and World Bank
16	Zhu, QH; Tian, YH; Sarkis, J (2012)	Firm	Environment	Quantitative	Authors' dataset of Chinese enterprises which obtained ISO14001 or eco-labelling 1 certification from 1996 to 2009
17	Perkins, R; Neumayer, E (2012)	Country	Environment	Quantitative	Authors' dataset of global automobile emission standards
18	Costantini, V; Crespi, F (2008)	Country	Environment	Quantitative	Secondary data from COMTRADE database
19	Techatassanasoontorn, AA; Kauffman, RJ (2014)	Country	ICT	Quantitative	Secondary data of digital wireless phone penetration growth data from national statistics, ITU, World Bank, GSM World, CDMA Development Group
20	Friebe, CA; von Flotow, P; Taube, FA (2014)	Country	Energy	Mixed	Archival data, interviews
21	Unnevehr, LJ (2007)	Country	Agri-food	Mixed	Secondary data from Global trade-related technical assistance database (GTAD), WTO
22	Gosens, J; Lu, YL (2013)	Industry/network	Energy	Qualitative	Archival data, interviews
23	Perez-Aleman, P (2012)	Country	Agri-food	Qualitative	Archival data, interviews
24	Pietrobelli, C; Rabellotti, R (2011)	Country	Multi-sector	Qualitative	Archival data, interviews
25	Gao, P; Yu, J; Lyytinen, K (2014)	Country	ICT	Qualitative	Archival data, interviews
26	Sanner, TA; Manda, TD; Nielsen, P (2014)	Country	ICT	Qualitative	Archival data, interviews
27	Tong, X; Shi, J; Zhou, Y (2012)	Firm	Environment	Quantitative	A survey of 636 hardware firms from 3 ICT hubs in China
28	Timmermans, K (2004)	Country	Health	Qualitative	Archival data
29	Srinivas, S (2006)	Firm	Health	Qualitative	Archival data, interviews

30	Foster, C; Heeks, R (2013)	Industry/network	ICT	Qualitative	Archival data, interviews
31	Ratnasingam, J; Wai, LT; Thanasegaran, G; Ioras, F; Vacalie, C; Coman, C; Lu, WM (2013)	Industry/network	Environment	Qualitative	Archival data, interviews
32	Soh, pH; Yu, JA (2010)	Firm	ICT	Qualitative	Archival data, interviews
33	Erdogmus, IE; Bodur, M; Yilmaz, C (2010)	Firm	Multi-sector	Quantitative	A survey of 94 managers of firms in Turkey
34	Nadvi, K; Halder, G (2005)	Industry/network	Health	Qualitative	Archival data, interviews
35	Schut, M; Soares, NC; van de Ven, G; Slingerland, M (2014)	Industry/network	Energy	Qualitative	Archival data, interviews
36	Roy, S; Misra, S(2012)	Country	Tourism	Qualitative	Archival data, interviews
37	Freitas, IMB; Iizuka, M (2012)	Multi-level (industry/firm)	Agri-food	Quantitative	Secondary data from ISO Survey ISO 9000 & ISO14001 adoption in Latin America, and a semi-structured survey of 62 Latin American firms
38	Fleisher, BM; McGuire, WH; Smith, AN; Zhou, M (2013)	Industry/region	Multi-sector	Quantitative	Secondary data from national R&D, patent laws
39	Allred, BB; Park, WG (2007)	Firm	Multi-sector	Quantitative	WIPO national patent data, firm level R&D data from Datadream (2446 companies from 35 countries)
40	Dube, L; Pingali, P; Webb, P (2012)	Theoretical	Multi-sector	Theoretical	Secondary data
41	Shiferaw, B; Holden, ST (2000)	Individual/household	Agri-food	Quantitative	A survey of 120 farm households
42	Kammen, DM; Kirubi, C (2008)	Industry/network	Energy	Quantitative	Secondary data from national statistics from multiple countries
43	Brown, DH; Thompson, S (2011)	Country	ICT	Qualitative	Archival data, interviews
44	Kshetri, N; Dholakia, N (	Industry/network	ICT	Qualitative	Archival data, interviews
45	Cardwell, R; Kerr, WA (2008)	Country	Agri-food	Quantitative	Secondary data from USDA
46	Fleury, A (1995)	Firm	Multi-sector	Quantitative	Secondary data
47	Amekawa, Y (2009)	Industry/network	Agri-food	Qualitative	Secondary data
48	Sha, KX; Song, T; Qi, X; Luo, NJ (2006)	Industry/network	Construction	Qualitative	Secondary data
49	Choung, JY; Hameed, T; Ji, I (2011)	Industry/network	ICT	Qualitative	Archival data, interviews
50	Preissel, S; Reckling, M (2010)	Firm	Agri-food	Qualitative	Archival data, interviews of 34 experts
51	Bekker, B; Eberhard, A; Gaunt, T; Marquard, A (2008)	Industry/network	Energy	Qualitative	Archival data, interviews
52	Schipmann, C; Qaim, M (2010)	Individual/household	Agri-food	Quantitative	A survey of 308 smallholder farmers in Thailand
53	Zhan, AL; Tan, ZX (2010)	Industry	ICT	Qualitative	A secondary data, interviews
54	Correa, PG; Fernandes, AM; Uregian, CJ (2010)	Firm	Multi-sector	Quantitative	A survey data of 7000 firms in 28 countries in Eastern Europe and Central Asia
55	Abbott, FM; Reichman, FH (2007)	Country	Health	Qualitative	Secondary data
56	Maskus, KE; Reichman, JH (2004)	Theoretical	Multi-sector	Theoretical	Secondary data
57	Bao, XH; Chen, WC (2013)	Country	Multi-sector	Quantitative	Secondary data from UN COMTRADE database, USDA (US Department of Agriculture), CEPII (Centre d'Etudes Prospectives et d'Informations Internationales)
58	Lai, ELC; Qiu, LD (2003)	Theoretical	Multi-sector	Theoretical	Archival data
59	Gao, P; Rafiq, A (2009)	Country	ICT	Qualitative	Archival data, interviews
60	Jandhyala, S; Henisz, WJ; Mansfield, ED (2011)	Bilateral trades	Trade	Quantitative	Author created database of bilateral trade agreements
61	Wu, K; Cai, H; Jiang, RA; Jefferson, GH (2013)	Country	Multi-sector	Quantitative	Secondary data from Penn World Table (PWT version 7.0) Index of patent rights, import and export data
62	Yu, J (2006)	Industry/network	ICT	Qualitative	Archival data, interviews of 18 senior managers from 5 indigenous and 2 foreign firms
63	Cook, J; Jeuland, M; Maskery, B; Lauria, D; Sur, D; Clemens, J; Whittington, D (2009)	Mixed	Health	Quantitative	Secondary data from Metlab, India, a survey of individuals on private demand of vaccine

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