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Standardisation of technological innovations in agriculture - Avenues for future research

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Abstract: This article explores the relationship between standards and technological innovation in agriculture. We examine current challenges in the design and implementation of standards for new agricultural technologies and identify avenues for future research. To this end, we introduce the reader to the literature on the standard-innovation nexus and present empirical examples of technological innovation in agriculture that reflect the interplay between standardization and innovation. We derive four research questions that we consider central to future research. Two of these questions relate to the standardization work of technical committees on innovation in agriculture, and two questions relate to the agricultural enterprises in which standards are ultimately implemented.

Keywords: Innovation, standardization, agriculture, standard-innovation nexus.

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1. Introduction

The literature on standards and innovation shows that standards can promote innovation and make innovation more effective (Blind, 2013; Swann, 2005; de Vries and Verhagen, 2016; Hawkins et al., 2017; González, 2022). Standards have become important regulatory tools that promote global trade and innovation, efficiency and quality, thereby helping to protect the economy, the environment and society (Blind, 2004; Blind and Gauch, 2009). For example, standards contribute to the safety, reliability and quality of services and technologies to ensure human health, environmental protection or information security (Utterback, 1994). They enable the modularisation of technologies and services (Teece, 2018). The benefits of modular design can be seen in aircraft or other vehicles, where certain parts of the aircraft can be tested, added or even removed without affecting the rest of the aircraft. For example, standards enable rapid, independent innovation in the supply chain, while keeping development and production costs low. Standards also reflect the state of the art in technologies and services. Where necessary, standards or the specific requirements of standards are also adapted to new technological achievements or services (Fried and Glaa, 2020).

While some studies suggest that standards support innovation, others argue that standards constrain technological development (Zoo et al., 2017) and reduce radical or exploratory innovation (e.g., Benner and Tushman, 2015; Terziovski and Guerrero, 2014). There are also other studies that report a mix of positive and negative effects (Blind, 2004; David and Steinmueller, 1994; Tassey, 2000). According to Blind (2013) and de Vries and Verhagen (2016), this results in an unclear overall picture due to the fact that authors consider different categories of standards and different forms of innovation (Blind, 2013; de Vries and Verhagen, 2016). Furthermore, to adequately address the complex interactions between standardisation and innovation, Blind (2021) calls for the development of standards to be studied first, followed by their impact on innovation. In addition, it is suggested that there are few case studies highlighting the impact of standards on specific innovative technologies/products (ibid). Given the growing public concern about food safety, we believe that the agricultural sector can be considered as a potential empirical case study for further investigation in the future.

The challenges related to the interplay between standards and innovation are the focus of the present study. The analysis of the relationship between standardisation and innovation, using the example of standardisation in the context of agricultural innovation, will provide a better and more complete understanding of the challenges of standards design and implementation in relation to technological innovation in agriculture. Our study is based on the literature on standards and innovation and on examples of technological innovation and standards in agriculture.

2. Standardisation-innovation nexus

Numerous conceptual and empirical studies have examined the relationship between standards and technological innovation over the last two decades. This relationship has turned out to be much more complex (Blind, 2022). On the one hand, some authors see a productivity dilemma: standards force firms to focus on improving routine tasks at the expense of reducing radical or exploratory innovation (e.g. Benner and Tushman, 2015; Boiral, 2003; Sutcliffe et al., 2000; Terziovski and Guerrero, 2014). According to Zoo et al. (2017, 7), “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”. In addition, standards or standardisation can be seen as an obstacle to product diversity, especially in the case of new products, because they can lead to monopolies, limit technological diversity and reduce consumer choice (Scheffman and Higgins, 2003; Salop and Scheffman, 1983; 1987). In the same vein, research on standardisation and innovation suggests that an abundance of standards, premature standardisation and delayed initiation of standardisation are likely to inhibit innovation (de Vries, 2021). Furthermore, restrictive and overly detailed standards may have a negative impact on innovation (de Vries and Wiegmann, 2017).

On the other hand, the literature on standardisation and innovation shows that standards can not only have a negative impact on innovation but can also serve to enhance it (de Vries and Verhagen, 2016; Hawkins et al., 2017). Similarly, some authors emphasise the positive role of standards in production innovation (e.g. El Manzani et al., 2019; Kim et al., 2012, Zoo et al., 2017). The literature suggests that the synergistic relationship between innovation and standardisation generates economic benefits. For example, standards accelerate the diffusion of innovation, provide information for innovation, and reduce innovation risk and time to market (Blind, 2013; Tassey, 2000). They facilitate “the emergence and diffusion of innovation by reducing transaction costs"(Zoo at al., 2017, 7). In addition, Blind and Gauch (2009) show how different types of standards facilitate innovation at certain stages of the R&D process. According to Loconto and Demortain (2017, 385), "standardization can therefore be defined as a process of controlling and framing diversity, rather than one of only reducing it".

Although there is a clear link between standards and innovation, there is no single answer to the question of whether standards constrain or enable innovation. Overall, standards seem to influence technological innovation in a variety of ways, enabling and constraining innovation in equal measure. Several authors, including, Langer and Fried (2020), Manders et al. (2016), Mangiarotti and Riillo (2014), Viardot et al. (2016), and Xie et al. (2016), conclude that their findings do not show a consistent relationship between the two and that there is no universally valid answer to whether standards constrain or enable product innovation.

Overall, standards appear to affect product innovation in several ways, enabling and constraining innovation in equal measure. For example, Foucart and Li (2021, 1) found that "the use of technology standards in recent years has significantly enabled a firm's incremental innovation while reducing its incentive to undertake radical innovation". The authors argue that the link between technology standards and radical innovation is consistent with path dependence on technology and the lock-in effect. Furthermore, the diverse characteristics, historical development, and evolving nature of standards are expected to interact with industry and market conditions, such as uncertainty, to influence the standards-innovation nexus throughout the technology life cycle (David and Steinmueller, 1994; Blind and Gauch, 2009; Lambert and Temple, 2015; Blind et al., 2017; Teece, 2018).

Similarly, Blind and Gauch (2009) have provided a broad perspective, highlighting the crucial role of research and innovation as catalysts for the development of new standards. More recently, Blind and van Laer (2021) found a significant correlation between research and standardisation and ISO standardisation activities, particularly in certain countries. This finding complements previous research indicating that firms with higher levels of innovation (Wakke et al., 2015) or countries with greater innovative capacity (Blind et al., 2021) tend to be more actively involved in standards development. Furthermore, de Vries and Verhagen (2016, p. 67) argue that "innovation in turn also impacts the standards, so a dynamic interrelation applies between different categories of standards and different forms of innovation".

Therefore, there is no universal answer to the question of whether standards constrain or enable product innovation. However, there are different ways in which the standard-innovation nexus is enacted by standard agents, which should be brought into focus rather than asking about a specific fit between standards and innovation (Fried et al., 2019). This highlights that, in addition to the external process of standard design, there is also an internal process of standard enactment. The process of designing standards is based on the possibility for standard agents in organisations to engage in standard enactment, for example by participating in standard setting processes in standard-setting bodies (i.e. being part of the technical committees which is a group responsible for the development and drafting of standards), by lobbying for legislation or by setting de facto standards through a dominant market position (Brunsson et al., 2012). Standard agents are stakeholders who take on or are entrusted with the responsibility of enacting compliant standards. In addition, standard agents can also be involved in the design of standards and influence the standard-innovation nexus. However, whether standards constrain or enable product innovation is a matter of judgement. Therefore, instead of asking for a specific fit between standards and innovation, future research should focus on different ways in which standard agents shape standards for technological innovation (Langer and Fried, 2020). In an agricultural context, standard agents can be, for example, farmers, machinery hire companies, industry associations, manufacturers of agricultural machinery, irrigation, fertilisers and agricultural electronics.

In summary, the study of the impact of standards on innovation poses several theoretical challenges. It requires the study of complex interactions (i.e. between standards design and enactment) and emergent forms of innovation. These challenges are related to the careful formulation of standard requirements by standards agents in technical committees (SBS, 2022) and the simultaneous continuous development of technological innovation and standards development (standards enactment in technological innovation). These challenges raise four different research questions, which are presented in section 4: 1) how are standard requirements formulated in such a way that they do not impede technological innovation, 2) what is the lack of expertise in technical committees that should ensure that technological innovation is understood in detail and that standard requirements are formulated appropriately, 3) what are the organisational context factors that contribute to effective implementation of standards in organisations, and 4) what is the standards landscape that potentially changes during the development of technological innovation. In addition, research on the standard-innovation nexus requires methodological improvements through the use of case studies that highlight the impact of standards on specific innovative technologies (e.g. innovative technologies in agriculture). This requires access to more precise and representative data on the use of standards in the agricultural sector.

3. Standardization-innovation nexus in agriculture

Not only has the agricultural sector been subject to increasingly stringent safety regulations for many years, but it is also exposed to different regulatory regimes in different global markets. Growing public concern about food safety has put pressure on government agencies to take a more prescriptive and proactive approach to regulating the food industry, including agriculture. It is also reported that food safety problems arise from inadequate government control and a lack of clear standards and procedures (Fearne and Garcia Martinez, 2005). Therefore, food safety has been identified as an area that has motivated increased standardisation in the eyes of opinion leaders and politicians. Exploring opportunities for greater public-private coordination is becoming essential for effective and efficient food safety regulation. Standardisation is a key measure to implement the European Commission's co-regulatory approach (EC, 2022). The underlying principle is captured in this passage:

> "The European standards organizations [standardization bodies] are responsible for identifying and elaborating harmonized standards and for presenting a list of adopted harmonized standards to the Commission. (…) New Approach Directives [coregulatory approach] do not foresee a procedure under which public authorities would verify or approve either at Community level or national level the contents of harmonized standards, which have been adopted with the procedural guarantees of the standardization process" (EC, 2000, 28).

To support high levels of reliable and ethically acceptable quality while not constraining technological innovation (cf. Mensah and Julien, 2011), effective standardisation in the agricultural sector must therefore incorporate the experience and knowledge of key stakeholders such as national governmental bodies, sectoral NGOs, special interest groups and value chain actors into food safety related standards. In addition, business operators need standards for technology and information exchange, and more help in implementing food safety regulations, in addition to improved food safety surveillance by government authorities.

Although the agricultural sector has been subject to different regulatory regimes in different global markets, the sector as a whole has not been subject to stringent safety regulations for many years. At the same time, technological innovations such as smart farming, and smart spraying technologies using robotics, drones, and artificial intelligence are recent developments where new standards need to be developed to support high levels of safety, reliability, and ethically responsible and acceptable quality (Blok and Lemmens, 2015). Standards can be valuable tools that provide guidance and best practices for machinery, tools, and agricultural practices (Wall et al., 2001). In addition, standards help to ensure that innovations effectively solve the problems they are intended to solve by outlining the framework within which they must operate (de Vries, 2008). For example, standards can solve the problem of mismatches between different generations of innovations during the development of an innovation. According to the Swedish Crop Protection Association: "*if you have a tractor and buy a new sprayer, for instance. And they don't understand each other, sometimes not even if it comes from the same manufacturer because of different generations of the development. So, there are a lot of improvements needed [..] [standards] will be contribution to the solution [of this problem].*" (Consultant from the Swedish Crop Protection Association). Below we present three examples of technological innovation in agriculture that reflect the interplay between standardisation and innovation. These examples are presented in chronological order of when the technological innovations and the corresponding standards were developed.

Three-point linkage

One of the brilliant ideas that paved the way for modern agriculture was the tractor as a general-purpose power unit that could be fitted with all kinds of agricultural implements. The world's first real tractor was introduced by John Froelich in 1892. For the first 50 years of the tractor era, farmers used the tractor to pull implements or trailers, and the interface was a chain or static metal hitch. However, in 1916 a process began that led to a very important innovation (Frankelius, 2012). Harry Ferguson was asked by the Irish Board of Agriculture how farming methods and technology could be improved in Ireland. On 19 March 1917, Ferguson and his colleague Willie Sands set off on an analysis tour. They found that tractors and the way they were used left a lot to be desired. Ploughs, for example, were pulled by chains behind the tractors, as had been the tradition since the beginning of the tractor era.

Ferguson and his team embarked on a process of innovation that resulted in seven patents (granted 1917-1925), a prototype tractor (The Black Tractor 1933) and finally a market launch (The Brown-Ferguson Tractor 1936) (see Figure 1). The concept was taken further through the agreement with Ford, who launched the 9N tractor (also known as the Ford-Ferguson tractor) in 1939. The concept was called three-point linkage.

Figure 1. A Ferguson tractor and a plow connected through the three-point linkage. Photo: Per Frankelius.

After Ferguson's patents expired, the three-point linkage became the industry standard. John Deere, for example, began offering a three-point hitch compatible with standard three-point implements with the introduction of the 20 Series two-cylinder tractors in 1956. In 1979, an ISO standard was issued by the International Organisation for Standardisation (ISO): "ISO 730-2:1979: Agricultural wheeled tractors — Three-point linkage — Part 2: Category 1 N (Narrow hitch)." It was described as follows: "Specifies the requirements for the attachment of implements or equipment to the rear narrow tractors by means of a hitch in association with a power lift. Applies to tractors with a maximum power at the drawbar up to 35 kW. Contains three figures which illustrate dimensions and configurations and includes three tables showing dimensions in millimeters."

ISOBUS

In 1966, Dickey-John introduced what was probably the first electronic device in agricultural machinery. It was a 'planter monitor' that could tell if there was a blockage in the airflow tube of a seed drill. From then on, the development of electronics in agricultural machinery exploded. Both machines and tractors became more advanced, and more machines were equipped with control systems that included a computer screen in the cab. But farmers began to see their cabs filled with different screens and displays for each of their implements. This was both frustrating and expensive. In addition, more and more electronic devices were being connected inside the tractor through point-to-point connections. This created a huge complexity with cables everywhere. But soon an interesting solution to this problem was born: parallel processes.

The background to this was that the company Vicon had set up an electronics department in 1983. In the same year they produced a baler controlled by microelectronics (HP 1600). On 30 May 1985, a patent application was filed with the title "A communication system" (patent 8501552) (see Figure 2). The inventors were Antonius Van der Voort van der Kley and Johan

Henning. It was a system with a standard data protocol and standard connectors that made it possible to integrate communication between tractors, software and equipment from many manufacturers. In 1998, Vicon was acquired by the Kverneland Group, which decided to release the patent in 2001.

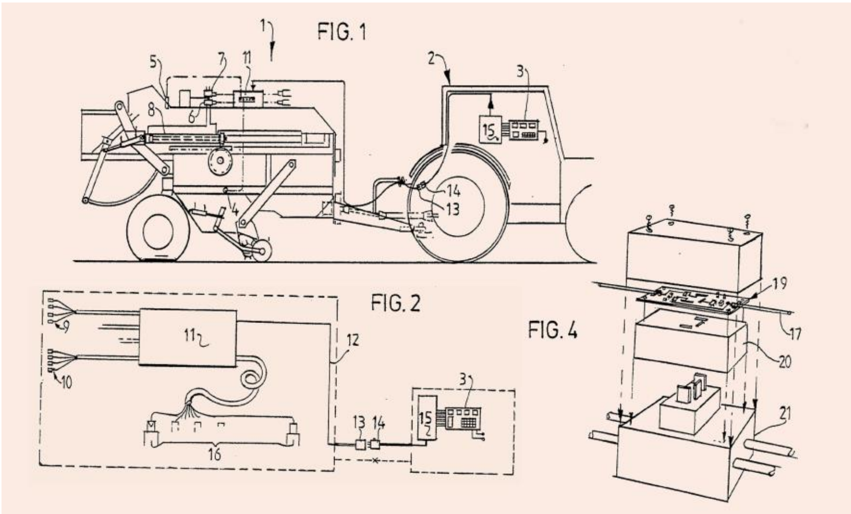

Figure 2. The ISOBUS patent "A communication system". Source: Patent 8501552.

Another part of the story was this: In 1985, Bosch developed the Controller Area Network (CAN) for in-vehicle networks to deal with all the cable chaos in vehicles. It was an integrated serial bus system for networking electronic devices. The automotive industry was quick to adopt CAN when it was launched in 1986. In 1993, CAN became an international standard: ISO 11898.

In 1991, the International Organisation for Standardisation (ISO) set up the SC 19 Agricultural Electronics Group. This group produced the ISOBUS standard, which was launched in 2001 as ISO 11783. In the early years there were some problems with quality and compatibility between different electronic devices and different versions of ISOBUS. To address this, the industry decided to create a neutral organisation to certify ISOBUS equipment and software. This resulted in the Agricultural Industry Electronics Foundation (AEF). This organisation certifies equipment and carries out many tests to verify quality. The standard is now administered by the Agricultural Industry Electronics Foundation. But the actual administration of the standard is done by the VDMA (Verband Deutscher Maschinen- und Anlagenbau) based in Frankfurt.

The ISOBUS standard is not static. It is a recent development: The original ISOBUS focused on controlling implements from the tractor (see Figure 3). But with the new concept called TIM (Tractor Implement Management System), the implement controls the tractor. TIM was probably invented by John Deere and then developed by the Agricultural Industry Electronics Foundation (AEF). Many TIM solutions were on show at Agritechnica 2009, but only on machines within the same brand. While the tractor has been the central symbol of agriculture, the time is coming when the tractor will be subordinated to the implement. In the near future there will be probably also robots controlled by the agricultural implement.

When we asked about criticism of ISOBUS, Peter Wahlgren, a farmer at Roma Gård (Gotland, Sweden), said: “It has both pros and cons, I think it becomes quite difficult to get an overview when you have to have many things on the same screen, for example the machine, the tractor and the GPS. Sometimes you also miss out on certain functions if you go to the tractor's screen via ISOBUS instead of the machine's own screen”. This means that ISOBUS needs to be developed further to address these issues.

Figure 3. Through ISOBUS most kinds of tractors can connect to most kinds of implements and use the same screen in the cabin for monitoring and control. Photo: Agtech 2030.

Big data standardization

The year 2013 was a breakthrough year for a phenomenon that is currently being seen in agriculture, namely cloud-based data platforms. For example, 365Farmnet was launched at Agritechnica 2013. 365Farmnet is a cloud-based, data-driven analytics system that integrates key parts of a farm's operations. The aim was to both track and manage all the processes and activities that can take place on a farm. The system included crop planning, farm maps, calendars, management of legislation and regulations, and specific functionalities for managing biogas plants, for example. The company was backed by major agricultural companies such as Claas, Amazone and Horsch. The system was launched in 2014. Another example is the Dairy Data Warehouse (DDW). It was founded in 2013. The business idea was to bring together large amounts of data and use AI to process it into valuable products for farmers. Today, DDW has data from more than 27 million cows connected to the system (see Figure 4).

To enable digitisation, data sharing and data-driven services, collaboration and standardisation are needed. Some experts have defined the problem as follows:

> "Modern farming requires increasing amounts of data exchange among hardware and software systems. Precision agriculture technologies were meant to enable growers to have information at their fingertips to keep accurate farm records (and calculate production costs), improve decision-making and promote efficiencies in crop management, enable greater traceability, and so forth. The attainment of these goals has been limited by the plethora of proprietary, incompatible data formats among equipment manufactures and Farm Management Information Systems (FMIS), along with a lack of common semantics (meaning) in the industry. Proposed partial solutions exist, e.g., the ISO11783.10 standard XML format is well-known and respected, but it is machinery specific and does not include business-process details needed by growers' FMIS." (Craker et al, 2018, 1).

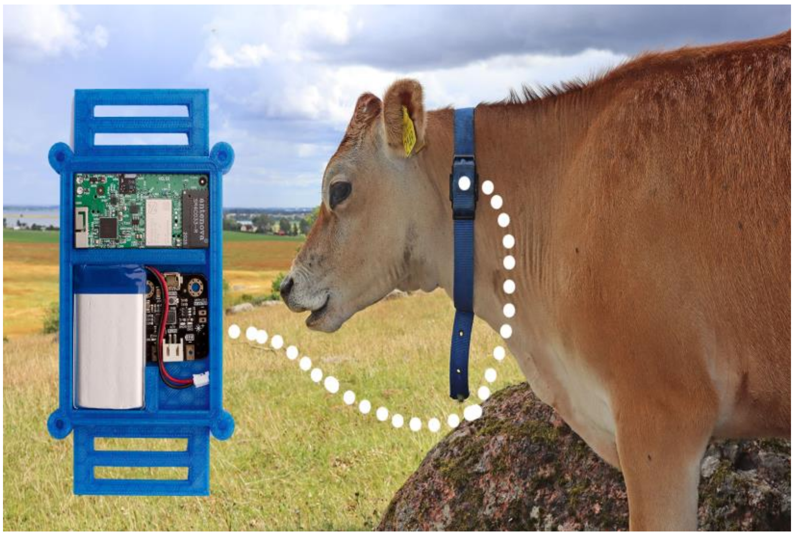

Figure 4. The sensor neckless on this heifer at Vreta utbildningscenter sends digital data continuously to the farmers dashboard. Photo: Agtech 2030.

Although agriculture lags behind many other industries in this area, the sector continues to develop in terms of big data standardisation. One interesting initiative was the "ISO 11783-11 online database", which was created in 2005 through a collaboration between the VDMA (Verband Deutscher Maschinen- und Anlagenbau) and the International Organisation for Standardisation (ISO). 637 object types were defined in February 2021, but two years later, in 2023, the number had increased to 57344. Another initiative was the AgGateway, an industry consortium of more than 200 agricultural companies. In 2013, this consortium launched the SPADE project to explore the feasibility of developing an open-source format conversion toolkit. This led to the creation of the Agricultural Data Application Programming Toolkit (ADAPT) committee, which is working on a common object model.

Data platforms in agriculture have evolved enormously, and continue to do so. The emergence of platforms and cloud computing in agriculture, phenomena not foreseen by many, illustrates the dynamic evolution of technological innovation in agriculture. This evolution has been faster than the development of standards for agricultural data. Thus, it is not clear how will the standardisation of agricultural data eveolve.

To illustrate the diversity and substantial growth of data platforms in agriculture, we have collected some examples of data platforms in agriculture from a historical perspective, as shown in Table 1.

Table 1: Data platforms in agriculture

Name of the platform	Year	Country	Actors behind it	Focus
The cow control	1951	Sweden	Växa	Animals
Lantbruksdata	1969	Sweden	Växa	Animals
RES-AGRI	2000	Europe	AgroEDI Europe	Mixed
ADAPT	2005	USA	AgGateway (Idealistic organization)	General
MyNew Holland	2010	New Holland (CNH)	New Holland, part of CNH	Machine
DataConnect	2013	Germany	365FarmNet Claas John Deere	Machine
MyJohnDeere	2013	USA	John Deere	Machine
Agrimetrics	2014	UK	NIAB, SRUC, Rothamsted Research and The University of Reading (financed by Innovate UK).	General
LiveLink	2014	UK	JCB	Machine
Fuse	2015	USA	Massey Ferguson, Fendt, Valtra, GSI, Challenger etc – in AGCO	Machine
Agrirouter	2016	Germany	DKE-Data consortium	Machine
MyEasyFarm	2016	France	DKE-Data, Telematics companies (e.g. the BHTronik telematics box)	Machine
JoinData	2017	Netherlands	Cooperative owned by several agricultural producer cooperatives.	Animals
Mimiro	2018	Norway	The producer cooperatives Tine and Felleskjöpet	Animals
Milk Forecast	2018	Netherlands	Dairy Data Warehouse (DDW)	Animals
Agripilot	2018	Poland	The Open Geospatial Consortium (OGC)	Machine
DataConnect	2019	Internationally	CNH Industrial, John Deere, CLAAS and 365FarmNet	Machine
Gigacow	2019	Sweden	SLU	Animals

MyCaseIH.com	2019	USA	CNH	Machine
MyPLM Connect Farm	2019	USA	New Holland, part of CNH	Machine
BDCA platform	2019	Brazil	Brazilian Association of Machinery and Equipment Industry (Abimaq)	Machine
DataLinker	2019	New Zealand	Red Meat Profit Partnership (RMPP)	Mixed
TopCow	2019	Netherlands	Dairy Data Warehouse (DDW), Skånesemin	Animals
Lantbrukets dataplattform	2020	Sweden	Agronod	Mixed
ATLAS	2020	Germany	European project IoF2020 (Internet of Food and Farm 2020)	Mixed
SenseHub	2022	Sweden	Merck (Växa Sverige)	Animals
Azure Data Manager for Agriculture	2023	USA	Microsoft	General
AgDatahub	2023	France	the FNSEA, the Avril group, the agricultural cooperation, and the chambers of agriculture	Mixed

To summarise the learning points from the examples presented, it can be concluded that the agriculture sector is highly innovative, and that technological innovation moves faster than the standardisation. Moreover, the examples show that there is an increasing number of patents which are declared to be essential to technology standards (Bekkers et al., 2012). However, according to Shapiro (2001), a high number of complementary patents owned by distinct companies could result in patent thickets, impeding technological innovation. Interestingly, standards that are subject to Standard-Essential Patents (SEPs) exhibit a more continuous pattern of technological advancement. The presence of SEPs correlates with a notable increase in the frequency of continuous upgrades in standards. In contrast, standards subject to SEPs are considerably less likely to undergo discontinuous replacements (Baron et al., 2016). Lastly, the examples prove that innovation and standardisation are closely linked, and that standardisation is crucial for the development of agricultural methods and technologies. The link between standardisation and innovation is clear in all the examples presented but needs to be explored in detail for technological innovation in agriculture.

4. Avenues for future research

In this section, we examine the standards-innovation nexus in agriculture and draw preliminary conclusions on potential implications for further research. First, we could identify two arenas for future research on the standard-innovation nexus. Both arenas (A and B) involve standard agents as the link between the design and implementation of standards (see figure 5). Standard agents are stakeholders who take or whom are given responsibility for standard creation and standard compliance, including regulatory affairs managers, quality or safety managers, and other organizational members (Langer and Fried, 2020). On the one hand, in some situations the design of standards is carried out by standards agents such as standardisation bodies and their technical committees (research arena A). On the other hand, there are situations where standards are implemented by standards agents such as agricultural manufacturers or farmers (research arena B). Two research questions are developed for both research arenas.

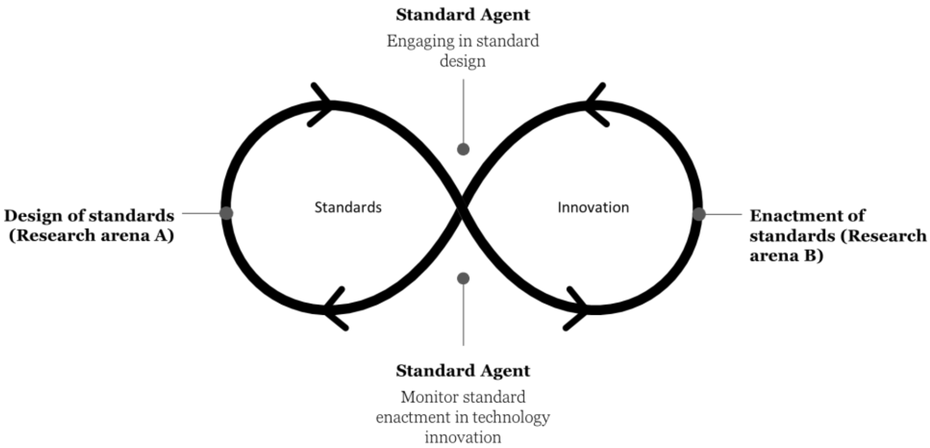

Figure 5: Research arenas of the standard-innovation nexus.

Research arena A: Design of standards

In this area of research, careful formulation of standard requirements by standards representatives in technical committees is generally sought, with functional requirements taking precedence over technical requirements (see figure 5). The first question therefore relates to the challenge of how to formulate standard requirements in a way that does not impede technological innovation in agriculture. The second question relates to the lack of expertise in technical committees to ensure that technological innovation is understood in detail and that standard requirements are formulated appropriately.

Research question 1. When working in technical committees, how do standards agents formulate standard requirements in a way that does not restrict technological innovation? We propose to use theoretical linguistics on formal rules and rule-following (Smith, 2001; Wittgenstein, 1958; see also Bloor, 1997; McGinn, 1997) for the analysis. Theoretical linguistics contributes to the understanding of syntax, semantics and the meaning of formal rules. Bartsch (1982, 57) observes that syntax, semantics and meaning differ when rules delineate "borders for permitted actions or operations, when they constitute a certain leeway in decision-making as well as the 'right' and 'wrong'". On this basis, we propose to analyse the formulation of standard requirements (rules) as a process, but also its final form, using linguistic tools.

Research question 2. What are the challenges of expert participation in technical committees? To answer this question, we propose to apply the concept of liminality to the analysis of the practice of technical committees in agriculture. Liminality is "a state of in-between-ness and ambiguity, as it applies to identity reconstruction of people in organizations. (…) This incorporates a dialogical perspective and defines liminal practices along with varying orientations of dialogue between the self and others" (Beech, 2011, 285). In addition to confirming in our data that finding expertise for the standardisation of knowledge-intensive technological innovations is often a lengthy endeavour, we also see that serving on a technical committee also involves two things that members have to deal with. On the one hand, they act as standardizers, trying to reconcile conflicting arguments in the process of standardization. On the other hand, members of technical committees serve different interests, such as corporate, industrial, consumer or environmental interests. These interests are often conflicting, but they are and must be reconciled in technical committee meetings in order to agree on a standard. Therefore, another theory could be helpful in investigating this dilemma of involvement and independence of technical committee members: the paradox theory (Jarzabkowski et al., 2013; Smith and Lewis, 2011). Using paradox theory, studies investigating technical committees can ask about members' understanding of their membership in standardisation decisions, which is influenced by the involvement-independence dilemma (cf. Anglin et al., 2022; Cunha and Putnam, 2019).

Research arena B: Enactment of standards

This study also identified sites where technological innovation is constantly evolving, and where standards finally take on their meaning and impact, i.e. where the effectiveness of standardisation becomes visible (research arena B; see figure 5). For this research area, we also identified two research questions. One is to identify the organisational context factors that contribute to the effective implementation of standards in organisations. The other is to identify the relevant standardisation landscape, which may change with the development of technological innovations in agriculture.

Research question 3. What are the challenges in implementing standards in general and how do standards specifically affect technological innovation in agriculture? To answer this question, we propose to use the theory of standard enactment (Fried and Walgenbach, 2020) as an analytical lens. When standard agents transfer standard requirements into internal standard operating procedures, they initiate a process of making sense of standards (see also May and Burby, 1998). Furthermore, they reserve resources for the implementation of standards, installing new roles such as compliance managers and procuring documentation tools, for example. Finally, internal and external sanctions and incentives are considered to motivate standard-compliant practices. According to the theory of standardisation, how well these three aspects - raising awareness, providing resources, and creating and observing incentives and sanctions - are harmonised will have an impact on the quality of standard implementation, but also on whether technological innovation is still possible at the same time.

Research question 4: When, how, and why do standard-related decisions take place in technological innovation processes in agriculture? According to Blind and Gauch (2009), different types of standards, such as semantic standards, interface standards or quality standards, can be important to integrate at different stages of an innovation process in order to reduce information costs, increase quality, or ensure safety. This includes standard-related decisions on the effective implementation of existing standards, but also participation in standardisation in technical committees when new standards are drafted, or existing standards are revised to adapt them to the latest technological developments. As reported, for example, by Gey et al. (2020) for software development or by Blind and Gauch (2009) for nanotechnological developments, this involvement in standardisation is important, bridging the two research arenas and allowing standards agents to show their agentic role in both standard design and standard enactment.

This study did have some limitations. First, this list of research questions focusing on the standardisation of technological innovation in agriculture can probably be expanded to include other questions on the standard-innovation nexus. Although not exhaustive, we are confident that these questions provide a starting point for further research on the standard-innovation nexus in agriculture and the potential challenges. Second, the examples of technological innovation in agriculture presented earlier could be also extended. The examples presented in this article could be used as a starting point for empirical investigations.

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