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SMART FARMING IN ITALIAN AGRICULTURE: ESSAYS ON ADOPTION AND DIFFUSION DYNAMICS SHAPING THE AGRICULTURAL DIGITAL TRANSITION

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Abstract

Nowadays the use of digital technologies in agriculture is a reality and signals a transition towards an evolutionary phase for the sector. Smart Farming Technologies (SFT) is the term used to define the set of digital technologies that, by creating a farm-level cyber-physical system - are making this transition possible. SFT are able not only to control and manage the farm system, but also to connect it to the many disruptive digital applications posed at multiple links along the value chain, which are shaping the on-going process of agri-food digitalization. However, the adoption of SFT has been so far limited, with significant differences at country-levels and among different types of farms and farmers.

The objective of this thesis is to analyze in detail what factors contributes to shape the agricultural digital transition and to assess its potential impacts in the Italian agri-food system. Specifically, this overall research objective is approached under three different perspectives. Firstly, we carry out a review of the literature that focuses on the determinants of adoption of farm-level Management Information Systems (MIS), namely the most adopted smart farming solutions in Italy. Secondly, we run an empirical analysis on what factors are currently shaping the adoption of SFT in Italy. In doing so, we focus on the multi-process and multi-faceted aspects of the adoption, by overcoming the one-off binary approach often used to study adoption decisions. Finally, we adopt a forward-looking perspective to investigate what the socio-ethical implications of a diffused use of SFT might be.

On the one hand, our results indicate that bigger, more structured farms with higher levels of commercial integration along the agri-food supply chain are those more likely to be early adopters. On the other hand, they highlight the need for the institutional and organizational environment around farms to more effectively support farmers in the digital transition. Moreover, the role of several other actors and actions are discussed and analyzed, by highlighting the key role of specific agri-food stakeholders and ad-hoc policies, with the aim to propose a clearer path towards an efficient, fair and inclusive digitalization of the agrifood sector.

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List of Acronyms

AD	Adoption Decision
AIRR	Anticipation-Inclusion-Reflexivity-Responsiveness (framework)
AKIS	Agricultural Knowledge Innovation Systems
DOI	Diffusion of Innovations Theory
DSS	Decision Support Systems
EE	Effort Expectancy
ERP	Enterprise Resource Planning
FC	Facilitating Conditions
FMIS	Farm Management Information Systems
HI	Hierarchical Integration
IS	Information Systems
IU	Intention to Use
MIS	Management Information Systems
PA	Precision Agriculture
PAT	Precision Agriculture Technologies
RRI	Responsible Research and Innovation
SAAS	Software As A Service
SCG	Supply Chain Governance Structures
SEM	Structural Equation Modeling
SFT	Smart Farming Technologies
SI	Social Influence
SME	Small and Medium Enterprises
TAM	Technology Acceptance Model
TCE	Transaction Cost Economics
TOE	Technology-Organization-Environment (framework)
TPB	Theory of Planned Behavior
TRA	Theory of Reasoned Action
UTAUT	Unified Theory of Acceptance and Used of Technologies
VRT	Variable Rate Technologies
ZIP	Zero-Inflated Poisson (regression model)

Chapter 1

1. Introduction

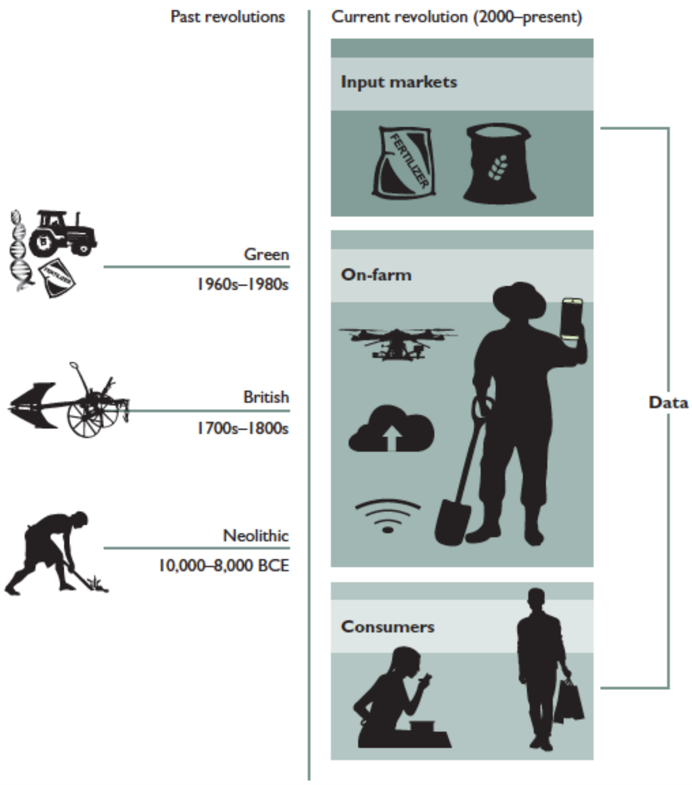
1.1. Innovation in the agricultural sector and the digital transition process

Background and motivations

"Agricultural innovation began with the invention of agriculture itself." (Pardey et al., 2010). With this sentence Pardey et al. efficiently summarizes the key role that innovations played in the evolution of agricultural systems, until the point where agriculture per se is the result of a continuous technological improvement in producing food. The World Bank report *"Harvesting prosperity – technology and productivity growth in agriculture"* (Fuglie et al., 2020), clearly explains the pivotal role that improvements to agricultural productivity, especially in low-income nations, has always had "to traverse the last mile toward eliminating extreme poverty" and, in general, to harvest prosperity from agricultural innovation. This report and several other authors (Christiaensen et al., 2011; Ligon and Sadoulet, 2018) posit that the transition from poverty has been achieved through increased agricultural productivity, with higher productivity providing food, labor, and savings to support urbanization and industrialization. The birth, development and expansion of markets, finance, and trade have surely contributed to productivity growth in agriculture; nonetheless, technological innovations has long been recognized "at the heart of the increases in agricultural productivity associated with agricultural transformation" (Schroeder et al., 2021, pp. 17). In fact, technological development has marked and continues to mark the succession of different agricultural r-evolutions (Pardey et al., 2010; Schroeder et al., 2021; Trendov et al., 2019); as shown in figure 1, the same invention of agriculture almost 10.000 years ago goes back to a shift from nomadic hunting and gathering to a systematized domestication of crops, by managing seed storage and planning planting phases. The new farmers started to select crop varieties, de facto adapting crop genetics to the environment that in the meanwhile was altered too, by modifying fields, weeding and irrigating. A second important technological "jump" in agricultural productivity can be observed in the period when these genetic innovations accumulated in years and years were combined with mechanical innovations; in the period between 17th and 19th centuries, a progression of innovations, emanating mainly from Great Britain, led to improved soil fertility management, more effective breeding practices, and better plows and powered machines. The third macro-chapter in this history of agricultural innovation can be identified with the development of new, more resistant crop varieties and the use of agrochemicals, and it has also been called "The Green Revolution". It started in the 1960s and was complemented by the rise of genetic modification technologies in the period between the 1990 and 2005. It enabled the economic growth in developing countries, by strongly reducing hunger and poverty.

The last (r-)evolution that is currently shaping agricultural evolution is defined in many ways, namely "digital agricultural revolution", "fourth agricultural revolution", "agriculture 4.0". It is characterized by the application of digital technologies to various agricultural processes able to collect, use, and analyze massive amounts of machine-readable data from various sources, to enhance decision making all along the value chain (Schroeder et al., 2021; Schwab, 2016; Trendov et al., 2019).

Figure 1 - Main revolutions in agriculture. Source: World Bank, 2021



The on-going digital revolution of agriculture is an evolving process that started already in 1980's, mainly with the diffusion of computer-based farm management information systems – FMIS in technologically advanced agricultural systems, especially in US (Batte et al., 1990, 1995; Batte and Arnholt, 2003). In this period, the main applications were limited to primary farm business uses such as financial accounting, correspondence, crop and livestock record keeping. In fact, this was the period of a first *digitization* of agriculture, consisting in the technical conversion of analogue information into digital form (Autio, 2017). With the enhanced sophistication of the digital technologies, able to collect, process and elaborate site-specific and spatial data, these tools started to provide enriched context-specific information to support decision-making at farm level: precision agriculture (PA) was born in those times, from mid 1980's to 1990's. (Pierce and Nowak, 1999; Tey and Brindal, 2012; Zhang et al., 2002). PA has widely populated the debate on digital transformation of agriculture so far and continues to attract most of the attention by scholars active in this field (Barnes, Soto, et al., 2019; van der Burg et al., 2019; Pierpaoli et al., 2013).

However, the technological progress moved a step forward within the agricultural evolution's process, by exceeding the pure digitization process typical of the digital applications at the single business or entity-level (as PA). Indeed, by combing the spread of internet since the 1990's and the consequential everyday connectivity with the use of sensors for (big) data collection, many technologies have become 'smart'; this meant that they started to be able to communicate autonomously, leading to the Internet of Things and Artificial Intelligence (see Khanna and Kaur, 2019; Lassoued et al., 2021; Zambon et al., 2019). This has led the previous process of *digitization* to a real process of *digitalization*, a term often used "to describe the socio-technical processes surrounding the use of (a large variety of) digital technologies that have an impact on social and institutional contexts, that require and increasingly rely on digital technologies". While in the manufacturing industry this has widely been defined as the evolution towards industry 4.0, in agriculture, forestry and rural areas there is not a common term to define such an agricultural transformation; Wolfert et al. (2017) defined Smart Farming as " a cyber-physical system" where smart devices – connected to the internet – control the farm system "by basing management tasks not only on location but also on data, enhanced by context- and situation awareness, triggered by real-time events" (pp. 70). In doing so, digitalization goes beyond the level of a single business or entity; on the one hand, it improves the data-intensive process of farm decision-making for resource allocation and management, by processing and analyzing more precise data faster and by providing tailored advice to the farm. On the other hand, by lowering the costs of linking agricultural operators to both upstream and downstream markets, digital technologies lead to both higher efficiency in transactions and increase in the transparency of the entire value chain, thanks to the improved access to information and product traceability (Schroeder et al., 2021). Existing outcomes of the ongoing digitalization process are digital platforms used to coordinate demand and supply in value chains, by linking on- and off- farm data and managements tasks (Barmpounakis et al., 2015; Tripoli and Schmidhuber, 2018; Wolfert et al., 2014). For these structural characteristics, digital innovations are thought to be able to tackle multiple inefficiencies prevalent in the agri- food system in a different way in respect to previous "revolutions". In facts, main differences with the past reside in the possibility to observe potentially disruptive digital applications coming from multiple links along the agrifood value chain, and not only from the farm-level.

Despite its innovative scope, the diffusion of digital technologies in agriculture is not free from challenges. In the first place, as for each innovation, there is always the challenge of its acceptance by users. This is especially true for agriculture, a sector that has always been considered traditional and low-tech, thus object of incremental rather than radical innovations (Capitanio et al., 2009; Martino et al., 2017; Materia et al., 2017). Farmers' behavior towards innovation's adoption and implementation has always been widely studied (Molinillo and Japutra, 2017; van Oorschot et al., 2018; Rogers, 1982, 2003). The same applies to digital innovations in agriculture: wide literature exists on the adoption of computer-based innovations, PA and other digital technologies that populated the initial digitization phase of agriculture (Alvarez and Nuthall, 2006; Pathak et al., 2019; Pierpaoli et al., 2013; Tey and Brindal, 2012). Nonetheless, when the focus moves to the latest digitalization process, very few scholars have analyzed the differences that exist in respect to the previous digitization phase, from the adoption point of view (Giua et al., 2020; Shang et al., 2021). Most of the existing literature that analyzes the adoption determinants primarily focus on farm or farmer-related characteristics, by often neglecting the role of several other aspects such as the external, institutional and organizational environments that do play a fundamental role in the current digital transition, given the interconnection with the entire value chain cited above (Pesce et al., 2019; Wolfert et al., 2017).

Secondly, the high-paced rhythm of technological evolution poses several challenges at both technological and socio-economic levels; on the one hand, the continuous technological evolution of digital tools and the associated raising amount of data produced, pose some issues in terms of data governance, difficult integration/communication among different devices, unclear data valorization and value distribution (Bronson and Knezevic, 2016; van der Burg et al., 2019; Klerkx and Rose, 2020; Malley et al., 2020). On the other hand, as many radical innovations before, digitalization of agriculture will strongly impact with disruptive effects various agents participating to the agrifood system. There might always be the risk to have a competition scenario strongly affected by radical technological innovations, with large, highly technologically advanced actors capable of destabilizing situations of perfect competition[1].

[1] It might be this the case of a technological monopoly/oligopoly run by few digital technological providers in the field of proprietary digital ecosystems, see van der Burg, S., Bogaardt, M.J. and Wolfert, S. (2019), M. Kritikos (2017) and Bronson, K. and Knezevic, I. (2016)

Given the above-mentioned premises, the aim of this doctoral thesis is to specifically address the challenges concerning the digital transition that the Italian agriculture is currently experiencing. In doing so, this work started from the current, wide debate on digital innovation of agriculture, which surely shares some features with the rich vocabulary of the entire innovation literature. In line with Sunding and Zilberman (2001), we distinguish between two major research lines constituents of this vast literature: research on innovation generation and research on the adoption and use of innovation. This work will focus on the second stream and the following chapter will provide a more precise overview of the main research objectives, as well as the relative theoretical approaches used.

1.1. Objectives and theoretical lens to analyze digital transition

Diffusion and adoption of Smart Farming Technologies

With the aim to dig into the challenges concerning the transition to digital agriculture, this work will comprehensively research the dynamics of the diffusion of digital technologies. Following a longitudinal approach, this thesis aims at analyzing the past and current debates on the adoption of digital devices at a farm level, by specifically focusing on Smart Farming Technologies – SFT. In doing so, this work starts with a review of the literature on the adoption of a specific typology of SFT, namely farm-level Management Information Systems – MIS. Farm-level MIS represent the evolution of the first computer-based solutions adopted in agriculture, in a smart farming perspective (Fountas, Carli, et al., 2015; Tummers et al., 2019) and, in many cases, represent a key technology that connects upstream and downstream phases of the supply chain (Giua et al., 2020; Yang et al., 2018). According to last data regarding SFT diffusion in Italy, Farm-level MIS are the most diffused technologies among farmers and similar users (Osservatorio Smart Agrifood, 2021); in fact, these devices generally present a non-prohibitive cost/benefit ratio in respect to similar digital technologies, given also by their wide adaptation to different crops (Kernecker et al., 2020). With this purpose, the first chapter provides a literature review of studies on the adoption of farm-level MIS, with the aim to extend - when possible - the main findings to the rest of the remaining SFT. In particular, the study aims at exploring the main theoretical approaches used by previous studies on the topic and, even more importantly, to review the principal adoption determinants identified by previous scholars.

Innovation and institutions: an institutional economics approach to digital innovation diffusion

As a result of the literature review conducted, this thesis highlights as previous contributions emphasized individual characteristics of farmers and farms as main adoption determinants, without properly considering several other factors (technological, attitudinal, contextual, institutional etc.). This findings are in line with previous review works on other digital technologies (Giagnocavo et al., 2017; Shang et al., 2021), which stress the need to enlarge the view on potential adoption determinants when it comes to digital technologies use in agriculture. More precisely, as underlined by several researchers, the role that actors, conditions and institutions external to the individual decision makers might play a fundamental role in shaping adoption decision outcome. Interestingly, many agricultural innovation scholars argue that these findings might be the result of a clear tendency occurred in the past "innovation literature", to focus on adoption as a result of technology supply-push or induced innovation models (Klerkx et al., 2012; Leeuwis, 2004; Röling, 2009). The recognized limit of such approaches is to relegate a passive role to users (farmers and similar agricultural operators) as mere recipients of innovation. Consequently, the main adoption determinants are often been researched in individual characteristics of *adopters*, without considering with the same attention the key role played by institutional environment around them. Institutions here are intended as those rules that govern human interaction with uncertainty (Williamson, 1979, 1991) and, in particular, as the sets of rules and institutional arrangements which define product and process operational parameters within value chains (Bonanno et al., 2018; Gereffi and Fernandez-stark, 2016). The role of "organizational institutions" might be particularly important especially in the case of SFT, that are strongly interconnected with institutional and organizational dynamics relative to the supply chain (Schroeder et al., 2021). With these premises, the second objective of this work is to fill the research gap regarding the role played by external-institutional factors – around the individual sphere of decision makers - in shaping SFT adoption dynamics in Italian agriculture.

Smart Farming and Responsible Research Innovation approach

The third and last section of this work contributes to shed lights on how current digital transformation dynamics might itself shape a "structural transformation" of agriculture (Schroeder et al., 2021). Being digitalization of agriculture a vast and on-going process, an approach that is exploratory and forward-looking at the same time is deemed preferable to grasp future evolution scenarios. Indeed, many forward-looking approaches are frequently used to explore potential effects that radical innovations might have on the society, also in agricultural contexts (Adler and

Ziglio, 1996; Ilbery et al., 2004; Markou et al., 2020). Among these, Responsible Research and Innovation – RRI framework plays a pivotal role; this approach addressed mainly researchers and similar actors actively participating in R&D processes, with the aim to balance and correct unexpected innovation dynamics that have often resulted from technology-push models (Macnaghten, 2016; Von Schomberg, 2013; Stilgoe et al., 2013). RRI has been often applied in several domain (Chatfield et al., 2017; Groves, 2017; Ravn et al., 2015) given its proven effectiveness not only in anticipating potential impacts of innovations on the society, but also in stimulating reflection on which subjects are participating in the innovation process and which one might be included. Moreover, it stimulates reflections on what proposals and actions can be advanced to adjust courses of action, as well as on which subjects should be responsible for them. Following various scholars' call to apply such method on digital agriculture transformation (van der Burg et al., 2019; Klerkx et al., 2019; Rose and Chilvers, 2018), the final chapter of this work carries out a qualitative investigation with the aim to identify opportunities, risks, social effects and possible interventions that might shape the (socially sustainable) diffusion of digital technologies in the Italian context.

1.2. Contributions of the thesis

This thesis contributes to shed lights on the on-going process of digital technologies diffusion in the Italian agriculture. In doing so, this is among the first contributions which comprehensively analyzes SFT adoption and the broader diffusion process, by using different perspectives of investigation and dedicated methodologies. Indeed, this thesis presents several elements of novelty. Firstly, this work grasps from the very beginning the revolutionary significance of the digitalization phase of agriculture, by focusing on the wider group of SFT as encompassing the PAT. This allowed to focus more precisely on the adoption of specific technologies within SFT, such as the FMIS. These technologies present some key characteristics which might favor their adoption at the farm-level more than other SFT (first among all, the versatility on more farm operations and the favorable costs/benefit ratio), thus a potential, facilitated digitalization process starting from upstream phases of the supply chain. Given the importance of this group of technologies, the second chapter of this thesis highlights and summarizes the key factors that need to be considered when focusing on their adoption.

Furthermore, the specific focus on SFT allowed us to frame the analysis of the whole adoption process in a more detailed and comprehensive way, such that their high interconnection with the rest of the supply chain is considered in the study and represents a second point of novelty of this thesis. In fact, the third chapter contains an empirical adoption study on digital technologies in

agriculture that a) considers several SFT adoption determinants, including adopters' individual characteristics and the role of organizational institutions, on both the moments of intentions' formation and actual adoption decision; b) specifically investigates the role of organizations (*organizational institutions*) in the whole adoption process, by highlighting the important function that they might have and which is not currently perceived by farmers and similar farm-level decision makers.
The third point of novelty of this thesis is contained in chapter 4. To the author's knowledge, this is the first study which investigates the socio-ethical implications arising from the diffusion of SFT in Italian agricultural system. Moreover, the forward-looking approach used in the study, has allowed to depict some current scenarios of development of the whole agrifood digitalization process, as in the case of the competitive dynamics in technological supply's arena and/or in the policy-regulatory context.
Overall, the findings obtained from this thesis could contribute to give a deeper understanding of the main dynamics occurring in the digital technologies' diffusion process in Italian agriculture. As a result, several actors at different levels of the whole agrifood ecosystem might find various insights and implications on how to understand, valorize and regulate this revolutionizing process.

1.3. Overview

This thesis is composed of three individual essays which focus on specific aspects of the main topic introduced so far. Each individual study is included in a chapter that outlines its structure and ties the elaboration to the entire thesis discussion through introduction and conclusions.
Chapter 2 will present the structured literature review of past studies on FMIS adoption. The study clarifies what SFT are and why it is important to focus on them specifically. Moreover, it highlights main adoption determinants as well as the main theoretical frameworks used to frame adoption analysis. The findings from this chapter identify and describe the research gaps that will be addressed by the following studies.
Chapter 3 contains a study which empirically investigates SFT adoption at the Italian national level. The analysis starts from multi-faceted and multi-processes sides of adoption. In doing so, it uses survey data to a) investigate the moment of attitudes/intentions formation prior to adoption decision, by applying the Unified Theory of Acceptance and Use of Technology - UTAUT framework; b) analyze different adoption determinants in the moment of actual adoption decision, with a specific focus on the role of organizational institutions. In this case, the analysis is enriched with theoretical elements coming from Transaction Cost Economics - TCE and previous digital agriculture adoption literature.

Chapter 4 widens the view from the adoption phenomenon to the ongoing digital transformation process that is involving the entire agri-food sector. In details, this section contains a study which uses a Delphi approach to explore the socio-ethical implications that might derive from the digitalization of the Italian agrifood sector. A selected pool of experts is interviewed through two rounds of semi-structured interviews, with the aim to anticipate some of the societal consequences that this radical innovation might bring in terms of benefits, risks and impacts on the different actors' categories populating the agrifood sector. Moreover, the study collects, synthetizes and reports some proposals advanced from the various experts interviewed to make the agrifood digital transition socially sustainable.

To conclude, in chapter 5 the results obtained in previous chapters are discussed, to argue how each part of the study reveals one or more aspects of the investigated agrifood digitalization phenomenon. Chapter 6 draws the conclusions of the thesis.

Chapter 2

2. Management Information Systems in the agri-food sector: a structured literature review[2]

Introduction

As outlined in the previous sections, agri-food systems are on the verge of a new *revolution* based on the use of digital innovations throughout the supply chain (Lehmann et al., 2012; Trendov et al., 2019; Wolfert et al., 2017). Scholars apply different names to define this digitalization, including 'digital agriculture', 'agriculture 4.0' and 'smart farming'. That notwithstanding, there is common agreement on the central role that data play in the agri-food supply chain's virtualization (Verdouw et al., 2016).

Despite the general agreement on the beneficial effects that this revolution will have for the agri-food system in terms of greater efficiency, effectiveness and sustainability (Fabregas et al., 2019; Lehmann et al., 2012), the process of adopting innovative digital technologies requires resources and competences which not all the actors possess (Poppe and Renwick, 2015). For instance, the literature shows that among internal resources, farm size and financial availability can be important barriers to overcome, especially for small and medium enterprises (SMEs) (Bucci et al., 2018; Lawson et al., 2011). Among external resources, poor internet connectivity, data transfer and privacy concerns are just some of the factors reported as obstacles to the adoption process (Kernecker et al., 2020; Pivoto et al., 2019). In addition, not only resources, but also specific competences need to be developed by firms – the so-called dynamic capabilities (Teece et al., 1997) – in order to achieve a suitable digital transformation of their business (Bouwman et al., 2018; Warner and Wäger, 2019; Zahra and George, 2002).

Disparities in the process of adopting digital technologies might further aggravate the unequal distribution of value that already exists in certain cases between small-medium (especially in

[2] This study has been published in a peer-reviewed academic journal.

upstream production stages) and large players (downstream production stages, especially distribution and retailers). This is particularly true for the European agri-food productive structure which predominantly comprises SMEs (Capitanio et al., 2009; Food Drink Europe, 2016; Materia et al., 2017). Furthermore, the digitalization process can be quite different depending on the nature of the digital technologies and on the challenges that arise in different supply chain stages (Pivoto et al., 2019; Poppe and Renwick, 2015). In light of the above considerations, this first chapter aims to provide a more specific systematization of the factors that enable and hinder the adoption of different technologies.

To this end, the following research focuses specifically on the farm-level adoption of smart-farming solutions, since the digitalization of the supply chain's upstream stage is an essential condition to successfully exploit this revolution and ensure that all stakeholders benefit. Indeed, farmers (particularly in small and medium agri-food enterprises) have traditionally been reluctant to innovate (Long et al., 2016) and they often lack the required resources and competences, especially for human capital-intensive innovations (Dicecca et al., 2016; Materia et al., 2017; Warren, 2002).
Thus, this study is based on a comprehensive review of contributions from the scientific literature dealing with the adoption of farm-level digital innovations, with a specific focus on Management Information System (MIS) technologies, defined as a set of software systems used to support human decision making within farm management activities (Fountas, Carli, et al., 2015; Verdouw et al., 2015). This study reviews the theoretical frameworks used as well as the drivers and barriers, both within and beyond farm boundaries.
This chapter is structured as follows. Section 2.1 sets out the scope and the objective of the study by means of providing a definition of the technologies considered and presenting the research questions. Section 2.2 outlines the methodology and discusses the sources of literature considered. Section 2.3 describes the main results, including descriptive characteristics and the evidence gathered concerning the theoretical frameworks adopted and the main evidence found in the literature reviewed. Finally, section 2.4 includes a discussion of these findings together with a description of the main research gaps that will be detailed in the following chapters.

2.1. State of the art: scope and objectives

Management Information Systems at the farm-level

In recent years, a large number of digital technologies have become available for actors in upstream stages within agri-food chains. Amongst these, advanced Decision Support Systems (DSS) have garnered increasing attention, enabling farmers to make informed decisions not only related to farming practices (precision agriculture technologies), but also financial and managerial operations (Fountas, Carli, et al., 2015).

Amongst such software solutions, scholars have placed particular focus on the Farm Management and Information Systems (FMIS) category. Sørensen et al. (2010, pp. 38) define FMIS as "a planned system for the collecting, processing, storing and disseminating of data in the form of information needed to carry out the functions of the farm". In addition, they point out that FMIS can be considered "an integral part of the overall management system of a firm [...] and part of tools such as Enterprise Resource Planning (ERP) and overall Information Systems (IS)" (Sørensen et al., 2010, pp. 38). By contrast, ERP technologies are defined as standardized software packages which incorporate information systems for multiple business functions to create a single integrated system (Verdouw et al., 2015).

In fact, even if FMIS and ERP applications have followed different evolutionary paths, today they communicate and collaborate within agri-food enterprises' IT systems. On the one hand, modern FMIS were developed to organize the increasing amount of data generated by precision agriculture technologies and combine them with an economic and holistic management perspective (Fountas, Carli, et al., 2015; Verdouw et al., 2015). On the other, ERPs stem from manufacturing resource planning systems and the necessity to integrate both across and within the various functional silos found in modern manufacturing (Jacobs and Weston, 2007). Initially, the rigid standards of early ERP solutions were not well suited to deal with the complexity of agricultural biological processes. Nonetheless, new web-based and customizable ERP systems are much more flexible (Møller, 2005) and capable of ensuring the interoperability required to integrate "many FMISs, DSSs and many applications in between, all covering different aspects of farm management" (Verdouw et al., 2015, pp. 127).This is why various authors argue that integrating FMIS and ERP research can result in numerous and promising research opportunities that are worth investigating (Haberli et al., 2019; Verdouw et al., 2015).

Hence, for the purposes of the present chapter, the literature analyzed includes research conducted on the farm-level adoption of both FMIS and ERP, as well as the intersections between these two technologies. Given the fast-developing nature of digital technologies, by including contributions dealing with different versions of FMIS (both computer-based and mobile-based systems, apps, SaaS, etc.), this review provides the opportunity to consider as many different contributions to the topic as possible. In the rest of the chapter and the thesis, the term Farm level MIS refers to this combined group of management information technologies.

Research questions

The literature on the farm-level adoption of MIS has mostly focused on FMIS technologies. To the best of the author' knowledge, the first specific contribution dates back to the end of last century (Lewis, 1998). At that time, the technical characteristics and functionalities of the software and devices used were more akin to computers assisting agricultural production as compared to how FMIS are used today (Tummers et al., 2019). Amongst most recent contributions, Tummers et al. (2019) review the obstacles to FMIS development and adoption found in the literature, besides providing a more updated state of the art on device functionalities. Amongst these barriers, some are more related to technical traits such as data standards and system integration, while others relate more specifically to factors linked to lower adoption, such as the comprehensibility of the software, insufficient skills amongst farmers and regional/language barriers.

Although Tummers et al. (2019) refer to specific obstacles, FMIS adoption has been analyzed only partially and to determine the explanatory variables behind their diffusion, not as the actual object of study. In fact, to the best of the author's knowledge, the available literature still lacks a review which focuses specifically on farm-level MIS adoption processes.

This chapter thus aims to fill this research gap, identifying the drivers and barriers behind the adoption of these technologies. In order to effectively summarize and contextualize these determinants, this study also analyses the theoretical frameworks used in the literature, the aim being to understand which theoretical lenses scholars have used to identify adoption factors to date. Consequently, this study proposes the following research questions:

- **RQ1:** Which theories have scholars used to study the adoption of farm-level MIS?
- **RQ2:** What are the main determinants affecting the adoption of farm-level MIS?
  - **RQ2.1** What are the main drivers?
  - **RQ2.2** What are the main barriers?

2.2. Materials and methods

The process of searching, collecting, selecting and synthesizing literature occurred between September 2019 and January 2020, following the literature review's approach proposed by Hart, who defined it as "the selection of available documents (both published and unpublished) on the topic, (…) to fulfil certain aims or express certain views on the nature of the topic and how it is to be investigated, and the effective evaluation of these documents in relation to the research being proposed" (Hart, 1998, pp. 13).

This approach has been integrated with both specific guidelines on how to structure the review (Vom Brocke et al., 2009; Torraco, 2005) and existing examples of structured literature reviews

(Boehm and Thomas, 2013; Della Corte et al., 2018; Cronin et al., 2008; Giacomarra et al., 2020; Svejvig and Andersen, 2015; Tell et al., 2016), with the aim to clearly present the analysis and results. Therefore, the review is organized in the following three phases: (i) search strategy, (ii) screening and selection and (iii) data extraction and analysis.

Search strategy

The automated research component implied using two of the key high-quality digital libraries available: ISI Web of Science and Scopus. As recommended by Hart (1998), after different attempts to identify the most inclusive string, the final research query combined various sets of keywords such as Farm Management Information Systems, FMIS, ERP and adoption. Search results included journal articles, conference papers and proceedings, white papers, reports and book sections, all published in English as found in the most recent FMIS review carried out by Tummers et al. (2019). In order to take the technological evolution of these management systems into account while also aware of the quickly developing literature on information technology (IT) in agriculture, texts were limited to the 1998-2019 period, starting from the first review on FMIS available in these sources (Lewis, 1998). This search identified additional studies that were then added to the screening process through snowball techniques. These additional texts were added by manually browsing through references of works previously found via the automated search. A preliminary refinement of articles was based on selecting Web of Science categories pertaining to agricultural economics and policy, agriculture multidisciplinary, computer science interdisciplinary applications and management. A total of 849 studies were identified in these digital libraries (576 from ISI WOS and 273 from Scopus). An initial selection was carried out before downloading the studies, based on their titles and reading their abstracts. In this stage, each contribution related to FMIS design, use and adoption and ERP adoption at the farm-level was considered for further refinement. A final screened sample of 70 studies was downloaded from said digital libraries (35 from ISI WOS and 35 from Scopus).

Screening and selection

All the studies identified were imported into a single library and processed using Mendeley citation manager software. Using the "Check for duplicates" feature, 12 studies were deleted, reducing the number of papers retained for analysis to 58. The screening selection process was based on two steps as found in Giacomarra et al. (2020). First, the following inclusion criteria were established: (1) all studies which focused on FMIS (computer or mobile-based) and ERP adoption used in the agri-food sector; and (2) all studies which focused on FMIS design, development and technological evolutions (traceability, big data, cross compliance and cloud-based platforms). 9 additional studies were eliminated as a result of the previous step. Second, studies were further screened based on the exclusion criteria listed in Table 1 below.

The final subset included 35 studies for analysis and study (see Figure 1 below). It was not possible to access the full text of one study due to license restrictions and had to eliminate it from the sample. Moreover, 22 other studies did not satisfy the exclusion criteria indicated above, while an additional 9 works were eventually added to the final selection by browsing references of selected studies.

Table 1 - Second step selection criteria

Number of Exclusion Criteria	Criteria Description
Criterion 1	Studies indicating an adoption theoretical framework
Criterion 2	Studies focused on Farm Management Information System (FMIS) design and users
Criterion 3	Studies considering adoption process drivers and barriers

At this step, the author did not only consider academic contributions which focused solely on adoption. The focus of the study was expanded to consider on other types of studies dedicated to FMIS software design and development. This choice was made for several reasons. First, one deals with the user-centric approach found in several texts (Kaloxylos et al., 2012; Kruize et al., 2016; Sørensen et al., 2011), an approach which "assumes that the users' ideas and requirements reactions concerning the specific characteristics of the designed technology are integrated in the subsequent design" (Sorensen et al., 2010, pp. 45). As several scholars acknowledge, end-user involvement during the early stage of the devices' design and development makes it easier to satisfy user requirements and, as a result, make user acceptance and adoption more likely. An example of this approach is found in Nurkka et al. (2007), where data from interviews, questionnaires and farms visits served to identify users' needs, demands and capabilities before designing a specific MIS, recognizing, at the same time, problems and limitations that might occur in the adoption and use of such devices.

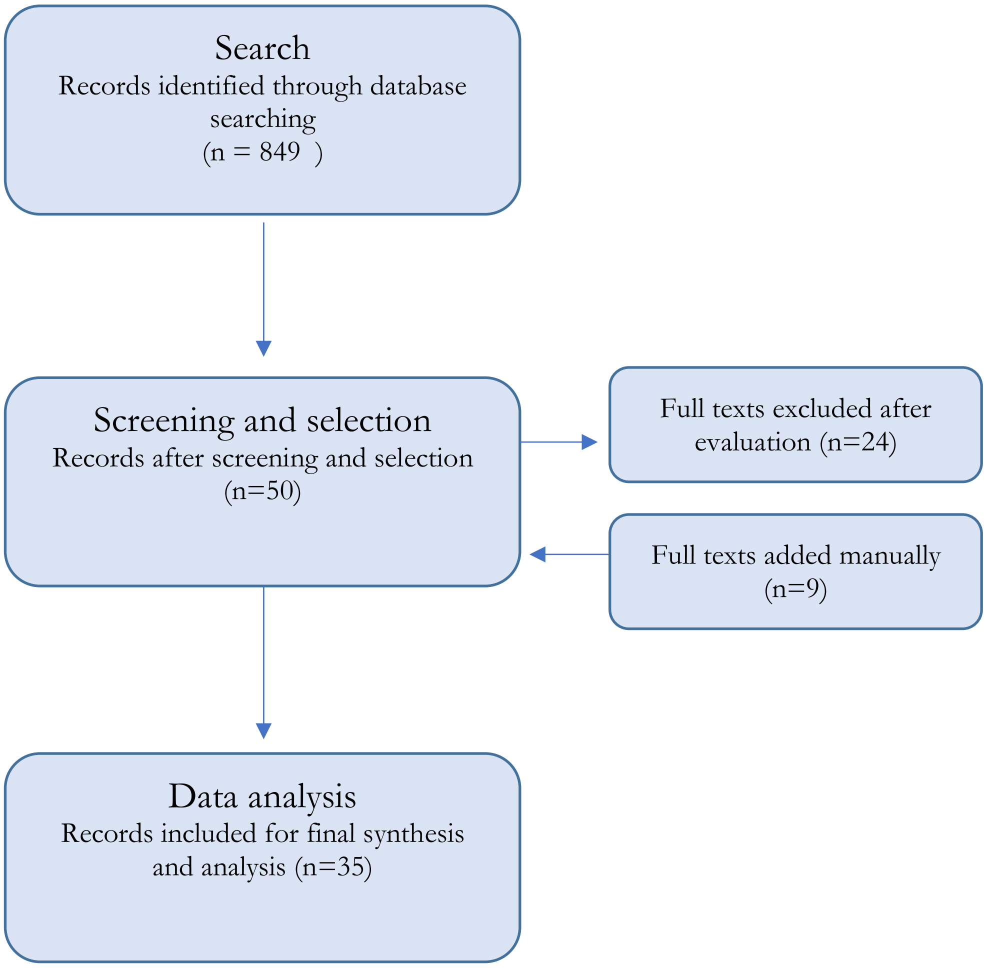
In addition, considering actual technology adoption and design simultaneously allows for a more complete picture on adoption determinants, including factors which might not be attributable solely to the adopter. This way, a more thorough understanding is possible, though not only of technology adoption, per se, but also some of its disparate consequences, one of which is the digital divide in the agri-food sector (Bronson and Knezevic, 2016; Trendov et al., 2019). This refers to the situation in which a substantial proportion of the population, identified by one or more shared characteristics, lags significantly behind others in the adoption of a new technology (Warren, 2002). Indeed, as Bronson (2019, pp. 3) argues: "'The bifurcation in the market for smart farming technologies may not simply be an adoption issue beginning on the farm (and with farmers); rather, it at least partly results from partial and normatively motivated design decisions which are helping to produce digital farming 'haves' and 'have-nots'". For these reasons, this chapter includes various types of studies (both qualitative-descriptive and quantitative-deterministic), the aim being to capture all the different determinants of farm-level MIS adoption identified until now.

Data extraction and analysis

All 35 papers were uploaded to the Atlas.ti 8 platform, a widely-used software to undertake qualitative data analyses and literature reviews (Haan et al., 2018; Hossain, 2016; Hossain et al., 2019). The author read the selected studies thoroughly and coded them with references to an extraction form organized in a matrix structure as suggested by Finfgeld-Connett (2014) and Leonidou et al. (2018), with the aim to "minimize human error and document this procedure for replicability purposes" (Leonidou et al., 2018, pp. 3). The matrix's structure is based on: (1) research questions for the literature review in keeping with Hart's recommendations (1998); (2) the data extraction method used by previous literature reviews to classify FMIS (Tummers et al., 2019); and (3) the reading of a sample of randomly-selected studies to iteratively adjust the structure (Hossain et al., 2019; Tummers et al., 2019).

The initial matrix structure comprised several features with the following classifications: general information (author, title, publication year and type of document); study description (sector, main theme, methods used, stakeholders involved, etc.); and adoption (theoretical framework – if any and including drivers and barriers). During the coding process, new themes were created when needed to categorize new codes. Most of the description elements were used to build statistic elaborations on the studies collected, and, together with the section focused on adoption, they served to answer the research questions posited.

Figure 2 - Flow diagram of the review process

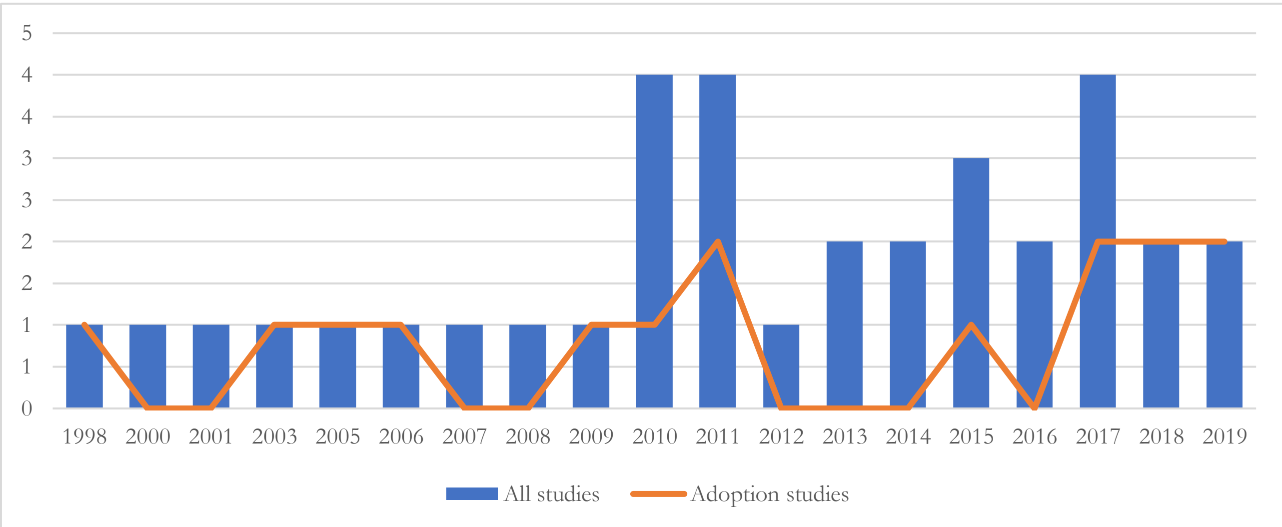


2.3. Results

This section summarises the data obtained distributed into two sections, in keeping with the review structures used by Radu (2016) and Tummers et al. (2019). The first focuses on descriptive statistics on the composition and main characteristics of the final sample of texts; the second provides findings to answer the research questions outlined above.

Trends regarding the number of publications and the composition of the sample of contributions studied provide interesting insights. The overall number of contributions is rather stable, apart from two peaks registered in 2010-2011 and in 2017 (see Figure 2). Both peaks denote the academic attention to evolved versions of FMIS with respect to more basic information systems available until that moment. In several cases, these studies may have been encouraged by international research projects (such as the EU-funded FUTUREFARM project or the SmartAgrifood and FiSpace projects, part of the European Future Internet Public-Private Partnership program (FI-PPP))[3].

Figure 3 - Time distribution of studies



As this review includes studies with research focuses other than just technology adoption, the author classified the contributions by the main themes addressed and synthesized the findings into the following key categories: adoption, software design and other types of studies.

[3] https://cordis.europa.eu/project/rcn/88262/reporting/en
https://www.fispace.eu/
http://smartagrifood.eu/

The "User adoption studies" category primarily comprises papers focused specifically on MIS adoption by agri-food users; the "Software design studies" group incorporates contributions that do not focus on adoption, per se, but on the development of a software architecture model. As explained above, due to the user-centric approach applied in these papers, it was possible to identify user requirements and barriers to FMIS adoption and use. Last, the "Other studies" category includes contributions with a broader focus. Some of the texts included in the latter group report on the state of the art of FMIS development and use, along with future perspectives (Allen and Wolfert, 2011; Fountas, Carli, et al., 2015; Kuhlmann and Brodersen, 2001; Tsiropoulos et al., 2017). Other contributions focus on the development of integrated platforms (software ecosystems) to make smart-farming technologies (such as FMIS) interoperable (Barmpounakis et al., 2015; Kruize et al., 2016).

In this study, the literature was classified according to the type of research conducted (qualitative vs. quantitative): 20 studies were classified as qualitative and the remaining 15 as quantitative[4]. Table 2 below shows how all these studies are distributed.

Table 2 - Type of Research (Qualitative or Quantitative) by Research Focus

	Qualitative	Quantitative	Total
User adoption	2	13	15
Software design	13	1	14
Others	5	1	6
Total	20	15	35

While almost all the qualitative texts are included in the "Software architectural models" and "Other studies" categories, only two of the fifteen studies on MIS adoption are qualitative. In the next sections, the additional details on adoption studies are discussed.

Theoretical and methodological approaches in adoption studies

Studies which focused specially on farm-level MIS adoption are listed in Table 3 below. A technological evolution occurred in the devices objects of adoption studies, from computer-based management information systems (Alvarez and Nuthall, 2006; Batte, 2005; Lewis, 1998; Tiffin and Balcombe, 2011) to more sophisticated, app-based and internet-connected versions (Carrer et al., 2017; Fox et al., 2018; Pivoto et al., 2019). Three papers focus on ERP adoption at the farm level (Haberli et al., 2017, 2019; Verdouw et al., 2016). The author checked the technological coherence

[4] It should be noted that, in some cases, quantitative methods (such as multivariate data analyses or econometric models) were preceded by qualitative methods such as interviews or focus groups (Haberli et al., 2019).

of this software with FMIS (discussed above) during the first selection step, since only contributions that studied ERP as aligned with FMIS were considered in adoption studies.

In terms of theoretical approaches, 11 of the 15 studies in this group used at least one conceptual framework to study technology adoption. The most used theory was the Diffusion of Innovation (DOI), devised originally by Rogers (2003, 1995). DOI theory studies the spread of innovations and how they proliferate through different channels over time and within a particular social environment. According to Rogers, the innovation-decision process involves five steps: (1) knowledge; (2) persuasion; (3) decision; (4) implementation; and (5) confirmation. These stages typically follow each other in a time-ordered manner. Adoption then depends on how individuals might perceive what Rogers (1982) defines as 5 innovation attributes, i.e., relative advantage, compatibility, complexity, trialability and observability.

Table 3 - Studies focused on adoption

Authors	Title	Year	Source	Type of study	Theory	Methodology	Scope	Publication findings
Lewis	Evolution of farm management information systems	1998	Computers and Electronics in Agriculture	Paper	DOI; Scheuing model (1989)	Quantitative, OLS regression	The study provides a description of FMIS' technological evolution and identifies factors associated with the use of these increasingly sophisticated technologies;	On average, use of sophisticated FMIS depends on individuals' characteristics (age and education) and common business factors (office equipment) rather than factors specific to farming activities.
Rosskopf & Wagner	Requirements for agricultural software – results of empirical studies	2003	European Federation of Information Technology in Agriculture (EFITA)	Conference Paper	-	Quantitative, descriptive statistics	The study investigates the decision process of farmers regarding agricultural softwares;	There are differences in identification of adoption determinants between scientists and IT experts (softwares' usability and costs) and farmers (lack of training and poor performances, inadequacy incompatibility);
Batte	Changing computer use in agriculture: evidence from Ohio	2005	Computers and Electronics in Agriculture	Paper	-	Quantitative, probit model	The study investigates use of computers for farm management among farmers from Ohio, US;	Adoption is more likely to occur among younger, more educated farmers, with larger farms and who worked year-around away;
Alvarez; Nuthall	Adoption of computer based information systems: the case of dairy farmers in Canterbury, NZ, and Florida, Uruguay	2006	Computers and Electronics in Agriculture	Paper	DOI; Behavioural modelling (Kline, 1999; Vanclay and Laurence, 1995)	Quantitative, structural equation modelling	Authors investigates farmers' information management behaviour in relation to agricultural software's adoption process in both New Zealand and Uruguay;	Adoption of computers for farm management depends on both farmers' characteristics (age, education, farm size and information system, time availability) and software features (usability and costs);
Mackrell et al.	A qualitative case study on adoption and use of agricultural	2009	Decision Support Systems	Paper	DOI; Orlikowsky model, 2000	Qualitative, in-depth interviews	The study analyses the adoption process of a decision support tool	Adoption success depends on technology compatibility, possibility to customise it and farmers' time availability;

	decision support system in the Australian cotton industry						for cotton farm management.	
Engler; Toledo	An analysis of factors affecting the adoption of economic and productive data recording methods of Chilean farmers	2010	Ciencia e Investigation Agraria	Paper	-	Quantitative, probit model	The paper studies the adoption of digital record-keeping tools by a sample of Chilean farmers;	Adoption of digital tools for record-keeping is mainly observed in younger, educated, risk-adverse farmers who lease land and participate to technology's transfer groups;
Lawson et al.	A four nation survey of farm information management and advanced farming systems: a descriptive analysis of survey responses	2011	Computers and Electronics in Agriculture	Paper	-	Quantitative, descriptive statistics	The work presents results from a survey on perception of information systems technology by farmers from Finland, Denmark Germany and Greece.	Results show that adoption of new farm information system is more likely to be observed in younger and more educated farmers, with larger farms. Nonetheless, majority of respondents from all countries were unsure about benefits of new technologies;
Tiffin; Balcombe	The determinants of technology adoption by UK farmers using Bayesian model averaging: the cases of organic production and computer usage	2011	Australian Journal of Agricultural and Resource Economics	Paper	-	Quantitative, Bayesian modelling average & probit models	The study investigates technology adoption's determinants (in forms of organic production and use of computers for farm management) in UK farming;	Farm's size (in terms of number of workers), education and age of the farmers are the variables which influence the adoption of computers for farm management;
Verdouw et al.	ERP in agriculture: Lessons learned from the Dutch horticulture	2015	Computers and Electronics in Agriculture	Paper	DOI	Qualitative, in-depth interviews	The study analyses ERP adoption in Dutch horticulture industry;	Adopters are driven by benefits of this technology and the possibility to customize it, but major obstacles remains in a proper management for the implementation, together

								with the complexity and costs of the technology;
Carrer et al.	Factors influencing the adoption of Farm Management Information Systems by Brazilian citrus farmers	2017	Computers and Electronics in Agriculture	Paper	Microeconomic theory	Quantitative, logit & Poisson models	The study investigates adoption of Farm management information systems in Brazilian citrus sector;	Adoption is positively linked to production revenue of farms, technical assistance received and farmers' level of education and management confidence. Conversely, farmers' experience and contractual adjustments were negative factors;
Haberli et al.	Understanding the determinants of adoption of enterprise resource planning (ERP) technology within the agri-food context: the case of the Midwest of Brazil	2017	International Food and Agribusiness Management Review	Paper	DOI; TOE	Quantitative, structural equation modelling	The study analyses ERP's adoption determinants in Brazilian soy, corn and cotton sector.	It is found that adoption rate is positively affected by technology's relative advantage, farms' size, management support and technology readiness, while is hampered by complexity in usage;
Fox et al.	Towards an understanding of farmers' mobile technology adoption: A comparison of adoption and continuance intentions	2018	Americas Conference on Information Systems 2018	Paper	UTAUT	Quantitative, structural equation modelling	The study investigates adoption and use of farm management mobile-based technologies among both non-users and users.	Non-users are most likely to adopt the application when recommended by a peer; users' intention to continue to use is driven by usability and usefulness;
Ibrahim et al.	Factors Influencing Acceptance and Use of ICT	2018	Journal of Global Information Management	Paper	UTAUT	Quantitative, structural equation modelling	The study analyses what factors influence adoption of ICT technologies by small	Results show that on five hypothesized predictors, only performance expectancy, management characteristics and

	Innovations by Agribusinesses						and medium agribusinesses.	organizational size are found to positively influence adoption;
Haberli et al.	The adoption stages (Evaluation, Adoption, and Routinisation) of ERP systems with business analytics functionality in the context of farms	2019	Computers and Electronics in Agriculture	Paper	DOI; TOE; Inter-organizational Relations (IOR) theory	Quantitative, structural equation modelling	The study carries out a both qualitative and quantitative study which investigates determinants of ERPs diffusion in Brazilian agriculture.	Relative advantage, compatibility and right technological environment within the agribusinesses are found to be significant predictors of adoption;
Pivoto et al.	Factors influencing the adoption of smart farming by Brazilian grain farmers	2019	International Food and Agribusiness Management Review	Paper	Microeconomic theory	Quantitative, Poisson model	The study investigates adoption's determinants of Smart Farming technologies by Brazilian farmers.	For what concerns farm management softwares, handling time was perceived as a barrier, while benefits related to farm management and costs together with farm size were the drivers;

Verdouw et al. (2015) are the only scholars in this review who use DOI as a unique framework. Two studies (Haberli et al., 2017, 2019) integrate DOI with Technology-Organization-Environment (TOE), another widely-used theory in adoption studies (Molinillo and Japutra, 2017; Oliveira and Martins, 2011). The TOE framework identifies the process used by a company to adopt and implement innovations, taking into account the technological, organizational and environmental context (Tornatzky and Fleischer, 1991). Fox et al. (2018) and Ibrahim et al. (2018) applied the Unified Theory of Adoption and Use of Technology (UTAUT) (more details in section 3.3).

Adoption determinants reported in the literature

This section presents the major drivers behind the adoption of farm-level MIS found through the review. To ensure an efficient synthesis, only drivers coded at least 4 times are reported in this paper (Tables A.1.1 and A.1.2 in the Appendix) in keeping with Tummers et al. (2019).

Results show that the most recurrent drivers are technology usability, farm size and farmer education level. Pignatti et al. (2015) categorize FMIS adoption drivers into three different groups: the innovations' technological features; farm and farmer traits; and external environment features. This study applies this same classification.

The International Organisation for Standardisation (ISO) defines usability/ease of use as follows: "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" (Bevan and Carter, 2016, pp. 269). This driver can thus be considered part of the 'technological features' category. As found in Nikkilä et al. (2010), Rosskopf and Wagner (2003) and Alvarez and Nuthall (2006), important factors when deciding to adopt a given MIS include user-friendly interfaces and easy-to-use software to input data and retrieve data output from the system. Furthermore, the possibility of customizing a farm-level MIS or its flexibility is another driver included in this category. Indeed, when customized technologies meet farms' specific needs while providing standard functionalities, users are more likely to adopt them (Mackrell et al., 2009; Rosskopf and Wagner, 2003).

Another driver category is related to farm characteristics. Farm size – generally measured in terms of land extension but also in terms of gross sales in some cases (Batte, 2005) or the number of paid workers (Tiffin and Balcombe, 2011) – is the most recurrent driver. Larger farms have to manage more complex production processes and they need to gather and process more information (e.g., precision agriculture data); therefore, farm-level MIS have to organize management data and control complexity (Carrer et al., 2017; Pivoto et al., 2019). Another driver included in this category is the farm's initial technology, a factor which includes all the different technologies already in use on the farm (current IT systems, other smart-farming technologies, etc.) and which might favor the adoption of a complementary farm-level MIS (Alvarez and Nuthall, 2006; Lewis, 1998).

The third most recurrent driver is farmers' education, included in the user characteristics category. Several studies found that more educated farmers were more likely to adopt MIS (Alvarez and Nuthall, 2006; Carrer et al., 2017; Engler and Toledo, 2010; Kaloxylos et al., 2014; Lewis, 1998; Tiffin and Balcombe, 2011). As explained by Carrer et al.: ''Farmers with higher education manifest greater demand for information and stronger ability to evaluate the benefits of using computers as a tool to support management decision-making" (2017, pp. 16). Another user characteristic which might have a positive influence on adoption is the existing level of IT skills needed to use management systems, including familiarity with computers or information systems (Allen and Wolfert, 2011; Kuhlmann and Brodersen, 2001; Nurkka et al., 2007) and with internet usage (Kaloxylos et al., 2014). In addition, there are several important factors within this group related to users' beliefs, perceptions and needs which drive farm-level MIS adoption. Amongst the individual perception factors, several studies point to the perceived relative advantage. Rogers defines this as ''the degree to which an innovation is perceived as better than the idea it supersedes'' (1982, p. 213). In this sense, there are different, interconnected sub-dimensions regarding relative advantages related to farm management: the degree of economic profitability, costs, benefits in terms of time and effort, etc. Haberli et al. (2019), Rosskopf and Wagner (2003), Tsiropoulos et al. (2017) and Verdouw et al. (2015) determine that perceived benefits include greater transparency, greater integration and improved efficiency, as well as expected profitability and other aspects related to the economic dimension of relative advantage.

When only considering studies that specifically focus on adoption, the most recurrent driving factors are limited to farm and farmer characteristics, such as size, education and relative advantage. No recurrent drivers were identified in the external environment group of features.

This study applied the same analysis to adoption barriers (see Appendix, Table A.1.2). When applying the same categorization to factors which directly or indirectly impede adoption, it seems that technological features are the most relevant barriers.

As Tummers et al. (2019) describe, problems related to interoperability or system integration between FMIS and their components hinder "interchangeability" between applications and platforms, reducing their applicability and, thus, the future adoption of such technology (Kruize et al., 2016). For Rosskopf and Wagner (2003), an important requirement expressed by some farmers is the possibility of adapting/integrating new and old software. Interoperability issues are strictly connected to data standards, since a lack of industry-wide data exchange protocols causes difficulties in data exchange, thus limiting farm-level MIS applicability (Allen and Wolfert, 2011; Fountas, Carli, et al., 2015; Kruize et al., 2016). Another aspect related to technological features refers to concerns regarding data ownership, privacy and security, representing issues for users and possible adopters (Allen and Wolfert, 2011; Fountas et al., 2009; Kaloxylos et al., 2014; Zheleva et al., 2017).

Included amongst technological factors which hinder adoption more directly is the complexity of these technologies; this not only includes unintuitive or excessively complicated interfaces but, also, too many features when compared to users' actual needs, making farm-level MIS technologies difficult to implement, understand and use (Haberli et al., 2017; Nikkilä et al., 2010; Verdouw et al., 2015). This perceived complexity is one of the causes that makes these technologies time-consuming for possible adopters, especially in terms of learning how to use them (Alvarez and Nuthall, 2006; Pivoto et al., 2019), for example, when manually inputting data (Mackrell et al., 2009; Steffe, 2000). These aspects are inversely connected to usability as a driver as discussed in the previous section, underscoring how much software design influences its adoption.

Between the technological feature and farm resource categories, the cost of these technologies certainly plays a role in adoption decisions. For Allen and Wolfert (2011), farmers are reluctant to invest too much in this software due to lower farm profitability and high market volatility. Kaloxylos et al. (2014) report some concerns about the cost of other smart-farming technologies related to their implementation; these can be even more prohibitive in the case of smallholders or SMEs (Zheleva et al., 2017). Finally, when it comes to user characteristics, several studies cite age as a common adoption barrier (Allen and Wolfert, 2011; Alvarez and Nuthall, 2006; Batte, 2005; Fountas, Sorensen, et al., 2015; Lewis, 1998; Tsiropoulos et al., 2017). The common argument is that new generations of farmers are usually more educated and computer-skilled, thus more willing to use new technologies. Again, when only considering studies specifically focused on adoption, age is the most important adoption barrier (Alvarez and Nuthall, 2006; Batte, 2005; Engler and Toledo, 2010; Lewis, 1998; Tiffin and Balcombe, 2011). Interestingly, a limited perception of the benefits of these tools is another recurrent barrier. Indeed, as Rosskopf and Wagner (2003, pp. 653) explain: "[...] While the scientists saw the cost of technology and the lack of user friendliness as the main problems, the participants of this study thought that lack of training and failure to understand the possible benefits were the greatest impediments". In fact, cost is not found to be a recurrent barrier in these studies as opposed to their complexity in terms of the time required to assimilate these technologies (Alvarez and Nuthall, 2006; Mackrell et al., 2009; Pivoto et al., 2019).

No features from the external environment were included amongst the most recurrent barriers. The only barrier which might be considered to belong to this group is infrastructural deficiency, specially, the lack of network connectivity.

2.4. Discussion and conclusions

The aim of this chapter was to review the literature on farm-level MIS adoption. Given the fast development of these technologies and our attempt to consider all the possible contributions to the research topic, the study considered different types of information technologies used for farm management (both computer and mobile-based FMIS and integrated farm-level ERP systems) and extended the analysis to studies which do not only focus directly on adoption but also on software architecture design and development.

When it comes to adoption determinants, the results obtained confirm other scholars' previous findings (Pierpaoli et al., 2013; Tsiropoulos et al., 2017; Tummers et al., 2019), specifically, that technologies' technical features in fact seem to play an important role in shaping the diffusion of MIS at the farm level. On the one hand, "systemic" technical problems, such as a lack of interoperability amongst devices, a lack of data standards and elevated costs, can limit a given technology's full potential; on the other, another key issue that seems to determine farm-level MIS adoption and the intention to use the latter is users' individual perceptions (farmers and farm employees) of innovation attributes such as the technology's relative advantage, usability, complexity and possible customization. Furthermore, users' characteristics together with farm features are also important adoption determinants. Age, education level and existing computer skills (users' characteristics) as well as farm size and initial technology in use (farm features) are the most recurrent factors. When limiting the focus to studies which solely address adoption, the most recurrent determinant factors seem limited to farm size, user age and education and the technology's perceived relative advantage.

Research Implications

The main practical implications of this study stem from the provision of a comprehensive systematization of factors which might determine MIS technologies adoption at the farm level. In facts, the inclusion of both conceptual and empirical types of contributions can reasonably show that adoption drivers and barriers might be due not only to users' characteristics and resources but also to technology features (Bronson, 2019). This is particularly relevant if seen as a cause behind today's unequal access to technology, i.e., the digital divide (Bronson, 2019; van der Burg et al., 2019; Carolan, 2016). In this perspective, these results might be of particular interest and utility for policy makers, who might find strategic to acknowledge the relevance at the same time of different types of determinants of adoption, when defining proper policies and when aiming at guaranteeing a fair and inclusive digitalization of the agrifood sector. Moreover, technology providers and the related smart farming technologies' industry are another type of actors who might benefit from a deeper understanding of adoption determinants. It might be easier for them to understand and successfully satisfy the requirements their customers demand.

For what concerns the theoretical implications two factors are particularly important to underline. Firstly, this study deals not only with adoption determinants, but it provides a classification of the main features of adoption studies in terms of research focus, methods and theoretical frameworks used. Secondly and consequently, the results of this review allow to clearly identify the main, key research gaps on the broader theme of SFT adoption that this thesis will explore in the next chapters.

On the first side, this work shows that studies which focus specifically on adoption are mainly quantitative in nature (see Table 3). Looking at the evolution of these studies over time, it seems that, until 2019, scholars focused their attention predominantly on software design and development rather than on their adoption, though adoption analyses have grown in number due to the increasing attention paid to the whole group of smart-farming technologies (Kernecker et al., 2020; Knierim et al., 2019; Pivoto et al., 2019). When the theories used to investigate the adoption are analyzed, results show that some scholars have used different conceptual frameworks such as DOI and TOE together to capture all the relevant factors (individual and organizational) which might drive MIS adoption and implementation (Alvarez and Nuthall, 2006; Haberli et al., 2017, 2019; Lewis, 1998; Mackrell et al., 2009).

For what concerns main research gaps, this review underlines how the majority of relevant factors identified in the literature so far seem to be limited to the individual action sphere. Accordingly, in the studies considered, farmers (and, at times, both farm managers and farm employees) are generally considered the key decision-makers. Nonetheless, in Tummers et al.'s (2019) recent review of FMIS literature, a wider scope of stakeholders is considered in the implementation and use of modern FMIS in the agri-food sector, as occurred in prior studies (Barmpounakis et al., 2015; Kaloxylos et al., 2012). Moreover, in their review on Big Data and smart farming technologies, Wolfert et al. refer to a new possible network of stakeholders built around farms which might produce a major shift in roles and power relations amongst different players in existing agri-food chains: "We observed the changing roles of old and new software suppliers in relation to Big Data and farming and emerging landscape of data-driven initiatives with prominent role of big tech and data companies like Google and IBM" (2017, pp. 75). This suggests that not only actors but also factors beyond farms' or farmers' individual circumstances might play an even more relevant role in determining MIS diffusion and adoption. In this respect, especially when MIS technologies are considered part of smart-farming technologies with their related ecosystems and new stakeholder networks, an interesting research direction in studying adoption determinants, would be to extend the focus to the role of additional factors beyond individual dimension (Klerkx et al., 2019). In this regard, actors and organizational factors relative to the supply chain where farmers and farms carry out their activities, might play an important explanatory role in unravelling the adoption and diffusion in the entire agri-food sector's digitalization; these and other potential factors will be investigated in the following chapters.

Chapter 3

3.Smart Farming adoption: an extended empirical analysis[5]

3.1. Introduction and objectives

Among the wide range of literature that already investigated the diffusion of digital technologies in the agri-food sector, most of the studies focus on precision agriculture technologies (PAT). PAT are solutions able to "match agricultural inputs and practices to localized conditions within a field to do the right thing, in the right place, at the right time, and in the right way" (Pierce et al., 1994, pp. 17). These technologies (e.g. remote sensing, precision irrigation, variable rate technologies - VRT, etc.) started to be used since 1990s, especially in the arable sector and suitable productive territories (e.g. Unites States) (Pathak et al., 2019; Pierpaoli et al., 2013; Tey and Brindal, 2012). Nowadays, PAT are the most known and widespread group of digital technologies within the entire agricultural community, among farmers and other agricultural stakeholders. Over time however, digital farming industry is experiencing a period of great development and dynamism in terms of technological supply, being able to find applications limited not only to the single farms or other business' entity level, but also to the rest of the supply chain. The previously mentioned Smart Farming Technologies – SFT represent the clearer example of this technological evolution in agriculture: sensors, drones, weather satellites, intelligent software algorithms and robots together generate data that once combined, are able to provide not only agronomic, but also historical, weather, market, logistic and benchmarking information. As reported in van der Burg et al. (2019), "Smart farming is not such an established term yet as precision agriculture, but where precision agriculture is mainly taking in-field variability into account, smart farming goes beyond that by basing management tasks not only on location but also on data, enhanced by context and situation awareness, triggered by real-time events" (pp.2). Kernecker et al. (2020) considered precision agriculture as encompassed in SF technologies and, in line with Fountas et al. (2015),

[5] This study has been published in a peer-reviewed academic journal.

they categorize SFT in 4 groups, namely (1) recording and mapping technologies, which collect site-specific data for subsequent application, (2) tractor GPS and connected tools that use real-time kinetics to appropriately apply variable rates of inputs and accurately guide tractors, (3) apps and farm management and information systems (FMIS), which integrate and connect with mobile devices for easier farm monitoring and management, and (4) autonomously operating machines (e.g. weeding and harvesting robots).
When looking at the demand of such digital technologies, farmers are increasingly using different devices to carry out activities in their farms (Osservatorio Smart Agrifood, 2019, 2020, 2021). Nonetheless, important differences in rates of adoption can already be seen according to farm and farmers' characteristics (Gardezi and Bronson, 2020; Kolady et al., 2020; Paustian and Theuvsen, 2017; Pierpaoli et al., 2013) and, more widely, even at country-levels (Lawson et al., 2011). Indeed, despite the general attention for a fair digital agriculture's transition - expressed also in recent European policies (European Commission, 2020) - a well-balanced and homogeneous diffusion of these technological innovations among farms and farmers is far to be reached (Barnes, Soto, et al., 2019; Bronson, 2019; Pathak et al., 2019; Rotz et al., 2019).

Recent literature results seem to support the hypothesis that younger, more educated farmers with large, specialized farms are favored in the adoption process. This contributes to raising concerns about a possible digital divide which might arise between the digital farming "haves" and "have nots" (Bronson, 2019), as one of the consequences of agriculture's digitalization. At the same time, as outlined in the previous chapter, the wider and well established literature on PAT largely focused on aspects relative to farm structure (size, sales, sector or land tenure) or farmers' socio-economic characteristics (age, education, experience) (Kernecker et al., 2020; Tey and Brindal, 2012) as direct adoption determinants, rarely going beyond the individual dimension of farmers (Giua et al., 2020; Pathak et al., 2019). Such an approach to the study of the diffusion of technological innovations presents two main limitations that must be considered when the larger and more recent group of SFT is considered (Shang et al., 2021). Firstly, SFT are inherently interoperable, thus they imply a more complicated adoption process. As reported by Wolfert et al. (2017), these technologies are complex in that they require collaboration between many different stakeholders having different roles in the data value chain. Such multifaceted aspect of the diffusion process still needs to be focus of research that comprehensively investigates the determinants of SFT adoption at various levels, with particular attention to factors going beyond individual characteristics of adopters and non-adopters. Among these determinants, organizational factors are particularly important; on the one hand, organizations around decision makers play a crucial role, especially considering that the

implementation of SFT reaches an optimal functionality when data can be transmitted along the value chain. Indeed, the existence of a pre-defined organizational network underpinning the data value chain might be key for the efficient flow of information before and after the virtualization of the supply chain (Pesce et al., 2019; Verdouw et al., 2016). On the other hand, the existence of organizational facilitating conditions, able to equally support different types of farmers, might be particularly important to include even less technological and structured farms in such digital transition (Giagnocavo et al., 2017). Still, as recently pointed out by Shang et al (2021) organizational/institutional aspects are among the less investigated by previous literature.
A second aspect that deserves attention regards the research approach often used to frame the adoption of innovations (such as, digital technologies).In fact, adoption is often analyzed as a one-off binary decision with a list of several variable directly affecting the final outcome (Sunding and Zilberman, 2001; Weersink and Fulton, 2020). In contrast, various scholars argue that innovations' diffusion in agriculture can rarely be seen as a result of a simple yes/no decision, being rather similar to a dynamic learning process with more phases (e.g. knowledge, information collection, persuasion, evaluation and similar, see Klerkx et al., 2012; Rogers, 2003; Sunding and Zilberman, 2001). Although including all the sequential processes in empirical analyses might be difficult, identifying which factors and/or subjects affect the formation of attitudes and behavioral intentions before the actual adoption contributes to better understand and explain the diffusion of these technologies. Yet, few studies consider such a multi-step nature of the SFT adoption process, failing to include these and other important aspects in their analyses (Caffaro et al., 2020; Kernecker et al., 2020; Pivoto et al., 2019; Ronaghi and Forouharfar, 2020).

In the light of these considerations, the aim of the study included in the next chapter aims at investigating the adoption of SFT by analyzing both its multistep and multifaceted aspects. In this regard, particular attention is paid to the role played by the organizational environment throughout the whole adoption process. The work is structured as follows; section 3.2 reports the conceptual framework, which stems from the literature review on adoption studies focusing on digital technologies at farm level. In the same section, the theoretical models used to investigate the adoption of SFT are presented and re-specified to be adapted to the context. Section 3.3 contains the methodology with the description of the empirical analysis conducted, while Section 3.4 presents the results obtained. Finally, findings are discussed in section 3.5 while section 3.6 includes the implications, concludes and reports some limitations of the study.

3.2. Conceptual framework

Literature review

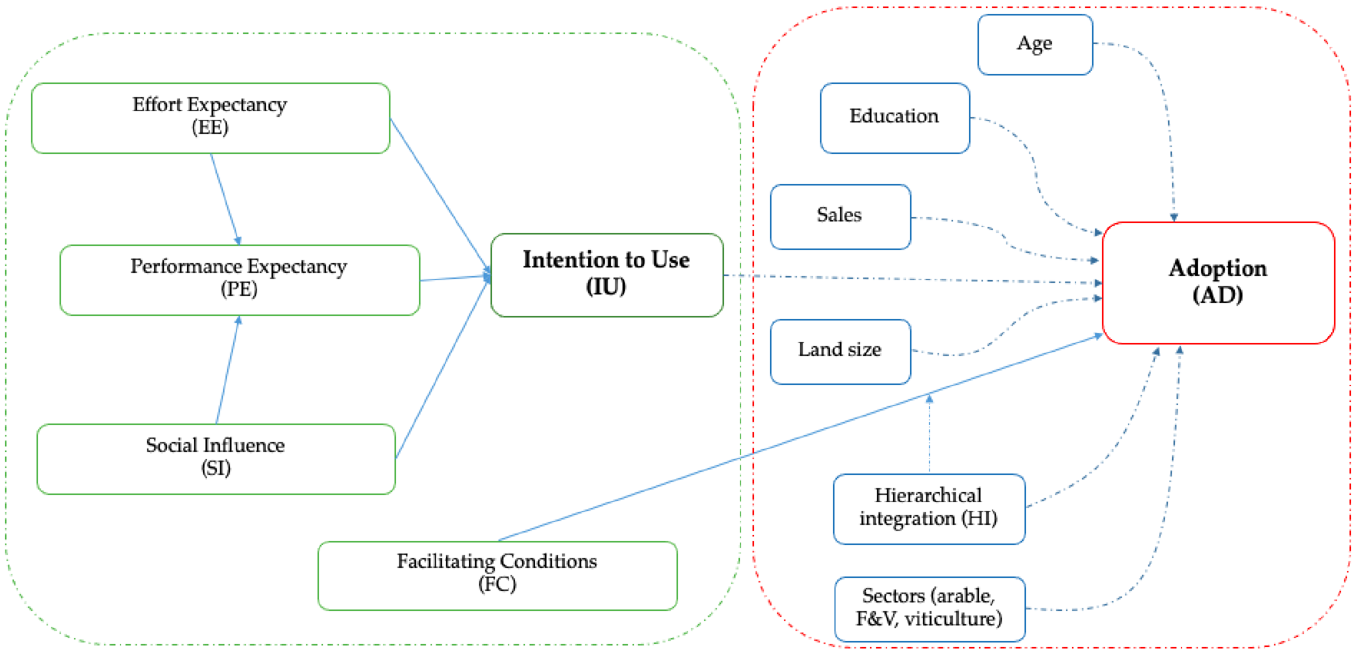
In line with other scholars (Knierim et al., 2019; Lioutas et al., 2019), this review section considers the intersection between the literature on PAT adoption and the studies that more recently focused on the definition of SFT. The systematic literature review by Tey and Brindal (2012) categorizes the determinants of PAT adoption into six groups of factors, namely: socio-demographic/economic, agro-ecological, behavioral/farmers' perceptions, technological, informational and institutional factors. The more recent review from Pathak et al. (2019) proposes an extended, alternative classification with nine main adoption determinants' components (i.e. innovation features, communication and influence, outer context, adopter characteristics, system antecedents and readiness for innovation, linkage, assimilation and implementation process). Although the classifications provided do not identically coincide, both agree on the prevalence of some typologies of determinants: farmers and farm characteristics, technological factors (e.g. complexity, usability, etc.) together with informational/communication factors. Moreover, both studies come up with similar conclusions: previous research poorly considered the whole, multifaceted adoption process tending to focus more on singular aspects (mostly relative to individual farm and owner characteristics). Tey and Brindal (2012) underline how behavioral and social aspects are among the aspects more ignored, while Busse et al. (2014) state that "an examination of social and organizational innovations (…) would provide a broader understanding of innovation mechanisms." (Pathak et al., 2019, pp. 1310).

Similar evidence is reported in studies focusing specifically on the adoption of SFT (Giua et al., 2020; Shang et al., 2021). Knierim et al., 2019, investigate the SFT adoption in Germany following a multi-actor approach; different stakeholders are considered (farmers, experts and multi-actor constellations) and both qualitative and quantitative methodology (i.e. descriptive statistics) are used. Socio-demographic characteristics as well as attitudes and expectations of farmers are analyzed. Although the study reveals interesting results about the whole innovation process from a qualitative perspective (i.e. they used the AKIS conceptual framework), the quantitative approach do not cover the causalities effects relative to the adoption determinants. Pivoto et al., 2019, investigate the same topic but in a different context (grain sector, Southern Brazil) and through a different methodology, namely logistic and Poisson regression models. Here SFT are considered as divided in four groups (as Fountas et al., 2015 proposed) and several determinants are identified depending on the technology considered (i.e. age, education, farm size) although none of these are statistically significant when SFT are considered aggregated. Moreover, a limitation of the study by Pivoto et al., 2019, is to not have considered the adopters' behavior as a possible adoption determinant. Attitudes, intentions and informational factors are instead considered in a recent study by Caffaro et al. 2020, where the SFT adoption is analyzed in North Italy. The Technology Acceptance Model (TAM - Davis, 1989) is used together with informational elements from the Diffusion of Innovation theory (DOI - Rogers, 2003) in order to investigate how different informational sources (personal-informal, personal-formal, impersonal) might affect attitudes and intentions regarding SFT. Results show that formal and informal sources of information have respectively a positive and a negative effect on the Perceived Usefulness (PU) that, in turn, positively affects the intention to adopt. Although the Authors consider informational aspects in the adoption process - one of the less explored factors in the literature - the study do not include socio-demographics characteristics of the respondents, nor the farms' structure as a variable that might have interacted with the model. Finally, the recent work from Ronaghi and Forouharfar (2020) estimates an extended adoption model using the Unified Theory of Acceptance and Use of Technology (UTAUT) by Venkatesh et al., 2003. This model allows the Authors to consider not only expectations, attitudes and intention of respondents, but also social and environmental-organizational influences that might affect adopters, as well as individual socio-demographic factors. Results show that attitudes towards SFT as well as social-environmental conditions play a positive role in influencing intention to use and use behavior, while individuals' age, experience and income show a negative effect. The Authors consider in their study the actual usage of Internet of things (IoT) technologies as dependent variable, without specifying which types of IoT technologies and how many. Nonetheless the model used allows to comprehensively investigate the adoption decision process.

Conceptualizing the SFT adoption model

The adoption studies discussed so far support the necessity to extend the analysis of the SFT adoption process to a wider set of determinants. This evidence was recently confirmed by Weersink and Fulton (2020) who highlighted how farm-level adoption studies should not only consider the dynamic nature of innovation diffusion, but also the different role that some factors might play at different moments of this process. With the aim to delve into these research gaps, this section introduces the research questions and the specification of the model used to investigate the SFT adoption. The conceptualization follows two main phases. First, to appreciate the multi-step nature of the process, the factors affecting farmers' intention to use are investigated through the UTAUT model (green dashed box, Fig. 4). Secondly, the determinants of the actual adoption are studied, focusing on factors that might directly affect the adoption decision (red dashed box, Fig. 4).

Figure 4 - Conceptual specification of the SFT adoption model



On both phases, particular attention is paid to the role of organizational conditions in shaping the entire process, with reference to facilitating supporting conditions and supply chain governance structures.

The remainder of this section presents, per each Research Question (RQ) addressed, the main assumptions and hypotheses behind both the Intention to use (IU) and the actual decision to adopt smart farming technologies (AD).

RQ1 - Which are the main factors affecting the intention to use SFT?

The completeness of the UTAUT model in exploring different attitudinal aspects of the innovation adoption process provides a useful theoretical framework to investigate the intention to adopt SFT. In their seminal work, Venkatesh et al. (2003), reviewed 8 principal theories[6] used to study technology adoption and merged them and the relative constructs into one unified theory of use and acceptance (UTAUT). In this model, the variables relative to the external, social-organizational environment are represented by two constructs denominated "Social Influence (SI)" and "Facilitating Conditions (FC)". The former is defined by the Authors as the "degree to which an individual perceives that important others believe he or she should use the technology" (pp. 451). The latter is defined as the "degree to which an individual believes that an organizational and technical infrastructure exists that supports the use of the technology" (pp. 453). In the present study, these variables are considered to capture the relevant effect played by the external organizational environment around farmers and farms.

In addition to the FC and SI constructs, the UTAUT model efficiently summarizes two further important attitudinal factors. Performance expectancy (PE) is defined as "the degree to which an individual believes that using the technology will help him or her to attain gains in job performance" (pp. 447); Effort expectancy (EE) is defined as "the degree of ease associated with the use of the technology" (pp. 450).

Although the UTAUT model has been originally applied in management and organizational innovation studies, it has also been previously adapted to various agri-food contexts. Beza et al. (2018) used the model to assess the mobile SMS technology acceptance from a sample of smallholder farmers. Additionally, Faridi et al., (2020) in their study in Rasht County, Northern Iran, incorporated the two models of UTAUT and Initial Trust Model (ITM) to assess water and soil conservation measures (WSCM) adoption. Finally, the above mentioned Ronaghi and

[6] These theories are: Technology acceptance model (TAM), the theory of reasoned action (TRA), Diffusion of innovation (DOI), the motivational model, the theory of planned behavior (TPB), a combined TPB/ TAM, a model of personal computer use and social cognitive theory.

Forouharfar (2020) and Michels et al. (2019) used the UTAUT models to investigate the adoption of different SFT, respectively IoT and crop management apps. With respect to the original version, the model is used in this study with some modifications, as found in previous literature (Beza et al., 2018; Li et al., 2020; Ronaghi and Forouharfar, 2020) and following research hypotheses are tested;

Performance Expectancy (PE)

Expectations about SFT performances have been investigated by previous studies through different constructs, such as the relative advantage from the DOI framework (Knierim et al., 2019) or the perceived usefulness from the TAM (Caffaro et al., 2020). For what concerns the UTAUT, PE is expected to be the strongest predictor of the intention to use/adopt (Venkatesh et al., 2003, pp.447). In the agricultural digital innovation adoption literature, the positive expectations of various decision makers about technologies are shown to affect positively their intention to adopt. On the base of such evidences, the following hypothesis is tested:

H1: *Performance expectancy positively affects the intention to use SFT.*

Expected Effort (EE)

In the recent review by Shang et al. (2021), the Authors allege that technologies' attributes such as complexity, perceived usefulness and similar farmers' attitude towards technology "have the potential to be more useful predictors for adoption decisions than characteristics of farms and farmers" (pp. 7). In digital innovation studies, technologies' ease of use (or complexity) showed to positively (negatively) affect adoption decision (Adrian et al., 2005; Pivoto et al., 2019; Vecchio, De Rosa, et al., 2020). Recently, Michels et al. (2020), showed how EE positively affected both IU and PE; with reference to the latter, it is expected that the higher the ease of use associated with a technology, the higher the performance expected by such technology (Davis, 1989; Michels et al., 2020).

H2: *Effort expectancy positively affects the intention to use SFT.*
H2a: *Effort expectancy positively affects performance expectancy regarding SFT.*

Social Influence (SI)

Social interactions are found to significantly affect innovation diffusion in agriculture (Kernecker et al., 2021; Klerkx et al., 2012; Ramirez, 2013; Scuotto et al., 2017). When the focus is on digital innovations' adoption, several actors are thought to exert social influence on decision makers. The support by consultants, extensions or peers was found to positively affect the intention to adopt digital technologies (Knierim et al., 2019; Kutter et al., 2011; Pivoto et al., 2019), while the influence by other farmers was found not always clear (see Shang et al., 2021). In the present study, we explore the role played by these different subjects around farmers and farms, with particular attention paid to the influence played by organizations or associations to which farmers belong; these structures are often believed to be the source of information and support that positively affects adoption decisions (Barnes, Soto, et al., 2019; Caffaro et al., 2020). Moreover, as found in Michels et al., SI is expected to exert a positive influence also on PE;

H3: ***Social influence positively affects intention to use SFT***.
H3a: ***Social influence positively affects performance expectancy regarding SFT.***

Facilitating Conditions (FC)
According to the original definition given by Venkatesh et al. (2003), the construct 'Facilitating Conditions' should reflect both the organizational and infrastructural support to the use/adoption decision. When it comes to the adoption of SFT, the existence of digital infrastructures (e.g. broadband) is fundamental, as well as other financial and technical resources. Several authors considered the effect of FC on both intention to use and actual adoption decision (Beza et al., 2018; Faridi et al., 2020; Michels et al., 2019; Schukat et al., 2019), although in the recent work by Michels et al. (2019), the effect of FC on IU was found to be not significant when assessed in the structural equation model. In this study, the FC construct is considered to be representative for both the infrastructural and organizational support that farmers and similar decision makers might consider in the decision to adopt or not SFT. To this aim, the following hypothesis is texted;

H4: ***Facilitating conditions have a positive effect on the SFT adoption decision.***

Intention to use (IU)
The UTAUT model postulates that the intention to use has a significant positive influence on the actual adoption and several empirical studies supported such hypothesis (Beza et al., 2018; Faridi et al., 2020; Zeng et al., 2016). Hence the following hypothesis is tested;

H5: ***The intention to use SFT has a positive impact on the actual adoption decision.***

RQ2 - Which are the main factors affecting SFT's actual adoption decision?
This study adopts the classification of SFT in 4 main typologies suggested by (Fountas, Carli, et al., 2015; Knierim et al., 2019). As found in Adrian et al., 2005; Aubert et al., 2012, we consider the adoption decision (our observed variable - AD) as the sum of selected technologies which respondents declared to use. Looking at the adoption determinants, socio-demographic variables are here considered as direct determinants, although in the original model by Venkatesh et al., 2003 they were considered to exert only a moderation effect on the variables affecting IU. Furthermore, acknowledging that organizational factors are among the aspects less investigated when it comes to digital technologies adoption (Shang et al., 2021) yet are relevant, this study adds them to the hypotheses tested in the model. With these premises, the following hypotheses are formulated.

Hierarchical integration (HI)
In this section, organizational factors are further analyzed according to the neo-institutional economics lens, as the sets of rules and institutional arrangements which define product and process operational parameters within value chains (Bonanno et al., 2018; Gereffi and Fernandez-stark, 2016). As proxy of the nature and the characteristics of supply chain relationships, we refer

to the notion of supply chain governance (SCG) defined as "the set of devices implemented within organizations, or among networks of organizations, to allocate and monitor assets and rights, providing the backbone to economic activities" (Ménard, 2018, pp. 143). As recently reported in (Kataike et al., 2019), various researchers described and "used different governance structures ranging within a continuum from market ("buy") to vertical Integration ("make") to explain coordination in food chains" (pp. 1851). Raynaud et al. (2005) reports a classification of governance structures in six types, following a hierarchical sequence, namely: spot market, relational contract, relational contract with an approved partner, formal written contract, equity-based contract and vertical integration. The same framework is used by Wever et al., (2010) to study quality management alignments in EU pork supply chains and later on by (Schulze et al., 2007), who studied attitudes of German farmers towards vertical integrated pork supply chains. Following this distinction, several authors explored how different forms of SCGs' hierarchical integration might affect innovation in the agri-food sector; Karantininis et al., (2010) showed how vertical integrated food supply chains boosted product innovation at firm-level in Denmark. More recently Martino et al. (2017; 2018) showed how different contracting solutions in the Italian olive sector impacted process innovation choices by olive millers. Finally, in the digital technologies' adoption literature, Carrer et al., (2017) proved that the existence of long-term production contracts at Brazilian citrus farm-level positively affected the decision of farmers to adopt farm management information systems. In this study, we draw from the classification proposed by Wever et al. (2010) and propose a measure of Hierarchical Integration (HI). In order to check whether HI might affect the SFT adoption decision, we attempted to detect whether the level of farms' commercial integration along the supply chain might: a) exert a moderating role on the relationship between FC and the adoption decision; b) directly positively affect the adoption decision, (Fig.2):

H6: ***Farms' hierarchical integration positively moderates the effect of FC on farmers' adoption decisions.***

H6.a: ***Farms' hierarchical integration positively affects farmers' decision to adopt SFT.***

Age

Decision makers' age has been extensively used as valid predictor of digital technologies' adoption and use in several studies (Batte, 2005; Daberkow and McBride, 2003). Often it is hypothesized that younger users are facilitated in dealing with digital technologies, especially when it comes to farmers (Tey and Brindal, 2012; Tiffin and Balcombe, 2011). For what concerns SFT, age was considered by several authors (Knierim et al., 2019; Pivoto et al., 2019; Ronaghi and Forouharfar, 2020) and generally showed negative effects on adoption. In accordance with literature results, the following hypothesis is tested:

H7: *Age negatively affects farmers' decision to adopt SFT.*

Education

In several papers education has been tested as having a potential positive effect on adoption (Barnes, De Soto, et al., 2019; Daberkow and McBride, 2003; Vecchio, Agnusdei, et al., 2020). The rationale behind these assumptions is that farmers with higher education level might better understand technologies' applications and utility. Since such a hypothesis recently has been contested, we test its validity:

H8: *Farmers' education positively affects the decision to adopt SFT.*

Farm Size (land used)

Farm size is one of the factors most frequently positively associated with SFT adoption in past studies (Shang et al., 2021), for several reasons - larger farms might benefit more from efficiency due to economies of scale, their management is generally more complex and data to support decisions might be particularly useful. Moreover, these farmers have generally more resources to invest in technological modernization. For these reasons, several researchers state that digital technologies are primarily designed and available for larger farms. Thus, the following hypothesis is tested:

H9: *Size of land used for farm activities positively affects farmers' decision to adopt SFT.*

Sales

Measures of farms' economic dimensions (income, sales, off-farm income) are often considered as adoption determinants in several studies (Barnes, Soto, et al., 2019; Kolady et al., 2020; Toma et al., 2018). Similarly to the case of farm size, the high costs involved in their adoption might require solid financial resources to adopt and correctly implement digital technologies. In this study, average annual turnover (sales) is considered as proxy of the economic dimension of farms and higher turnovers are expected to be positively associated with SFT adoption decisions.

H10: *Farms' annual turnovers (Sales) positively affect farmers' decision to adopt SFT.*

Sectors

Among agricultural sectors, the arable one has been the main focus of previous literature (Aubert et al., 2012; Kernecker et al., 2020; Michels et al., 2020; Paustian and Theuvsen, 2017): higher quality land and land size's availability have been associated with higher farm-level adoption of digital technologies. However, as noticed by Kernecker et al., 2020, fruit and vegetable (F&V) and viticulture have seen a greater adoption of farm management information systems in European contexts. In order to detect whether a specific sector might be more likely to be associated with a higher SFT use by relative farms, the following hypotheses are tested:

H11.a: *Farms' specialization in the extensive arable sector positively affects the decision to adopt SFT;*

H11.b: ***Farms' specialization in the fruit and vegetable (F&V) sector positively affects decision to adopt SFT;***
H11.c: ***Farms' specialization in the viticulture sector positively affects the decision to adopt SFT;***

3.3. Methods and sample

Data collection

A questionnaire composed of 40 questions was tested before being administered in the period October 2020 - January 2021. Most of the questions are Likert-scale survey questions (25), which guarantees the compatibility with the UTAUT model and its statistical elaborations. The attitudinal constructs are built through specific items which result from a review of the literature, starting from the original UTAUT model by Venkatesh et al. (2012, 2003). Given their significant application to the agri-food and the digital technologies' adoption context, we adapt various items retrieved from previous studies (Beza et al., 2018; Diekmann and Theuvsen, 2019; Faridi et al., 2020; Michels et al., 2020; Ronaghi and Forouharfar, 2020; Venkatesh et al., 2012) (see Table A. 2.2 in Appendix for more details).
Before the actual launch, the efficacy and comprehensibility of the survey were tested through pilot interviews with 8 farmers (from Emilia-Romagna, a region in North-East Italy). The pilot interviews were carried out via telephone and through different modalities; in some cases the survey was filled out by the respondents assisted by the author, the aim being to directly observe the interviewee's interpretation of questions and main concepts. In other cases, the survey was directly sent by email to the interviewees who were then asked to take notes and report feedbacks. The pilot interviews process allowed us to considerably improve both the formulation of the questions and the overall flow of the survey. Subsequently, given that the research was carried out in the middle of the COVID-19 pandemic, the Computer Assisted Web Interviewing (CAWI) approach was used. In order to obtain the largest possible adhesion by farmers, the author relied on existing databases to maximize farmers' reach and survey's responses. To this aim, we were granted access to one of the biggest private agricultural stakeholders' on-line community in Italy, run by the "Image Line" company[7]. Its community accounted for more than 250.000 registered users in January 2021, among which more than 50.000 are farmers. [8].

[7] Image Line is a company that provides information, communication and technology services for agricultural sector, with an expertise in management information systems and agricultural databases' offer (Cristiano et al., 2020).
[8] https://www.imagelinenetwork.com/

The survey was launched in December 2020 to a total sample of 51.400 farmers. At the end of January 2021, the total number of responses collected (partial and complete) amounted at 945 (1.84% response rate). After the elimination of incomplete responses and an exploratory analysis, data were cleaned in order to avoid repetitive responses.

Data analysis

The analysis is based on a sample of farmers distributed in the whole country. Firstly, descriptive statistics were calculated for an overview of the farmers' characteristics in the sample (Table 4). When compared to the national population, the respondents participating in the study are on average younger, more educated, with larger farms and higher income. Such a difference is probably due to the types of farmers registered in the Image Line community, on average more technologically advanced.

Table 4 - Sample descriptive statistics

	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.	NA's
Age	20	44	53	51.56	60	83	12
Size (hectares)	0.6	8	20.50	53.56	59.50	768	100
Education	-	second level secondary schools	second level secondary schools	-	bachelor/master degree	-	2
Income	-	€ 15.000 - 24.999	€ 50.000 - 99.999	-	€100.000-249.999	-	59

In order to investigate the causal relationship between the variables and the constructs described above, two different methodologies are used and both analyses are carried out through R statistical software (version 1.4.1103): Structural Equation Modelling (SEM) and Zero-inflated Poisson (ZIP) model. For what concerns attitudes and intention to use SFT, the SEM approach is adopted. The SEM is widely used in several disciplines such as management, socio-psychological, economics and organizational studies. It is a statistical method that allows to simultaneously analyze multiple causal relations occurring in a phenomenon. It consists of two main steps (Hair et al., 2019); firstly the measurement model is set-up and analyzed to evaluate reliability of the constructs used. Secondly, the structural model is run and results analyzed to infer about the causalities hypothesized.

For what concerns the actual adoption decision model, a Zero-inflated Poisson (ZIP) model was used to detect which variables act as determinants when it comes to both adoption or rejection choices and adoption of multiple technologies. In fact, adoption can be interpreted and analyzed in two ways; on the one hand, as a binary variable useful to codify the adoption decision - it is then equal to 1 when respondents adopted one of the SFT, 0 in the opposite case. On the other hand, the observed variable can be the sum of different technologies adopted, to reflect the adoption intensity for each observation. In this last case, when the observed variable is ordinal such that $y = i \; with \; i = 0, \dots, n$, the ZIP regression model allows to simultaneously investigate when $y_i = \begin{cases} y_i = 0 \\ y_i > 0 \end{cases}$ through two different estimation functions such that $\Pr(Y_i | y_i x_i, z_i) =$

$$\begin{cases} \varphi_i + (1 - \varphi_i) \exp(-\mu_i) & y_i = 0 \\ (1 - \varphi_i) \frac{\exp(-\mu_i) \mu_i^{y_i}}{y_i!} & y_i > 0 \end{cases}$$

where φ_i is the probability of the logistic distribution. With SEM model, total complete responses accounted to 474 (only Likert-type and multiple choice questions considered). When the ZIP model was run, the total sample reduced to 341 observations to avoid missing values in socio-demographic variables. Based on the methodological recommendations set out in the scientific literature concerning the estimation of SEM and ZIP models (Hair et al., 2019; Isgin et al., 2008) and considering the size of the samples used in similar works (Adrian et al., 2005; Beza et al., 2018; Caffaro et al., 2020; Gere et al., 2017; Karantininis et al., 2010; Ronaghi and Forouharfar, 2020), we argue that the sample selected is appropriate for the purposes of this study.

3.4. Results

Intention to use: Structural equation modeling (SEM)

Measurement model

A first complete measurement model - which included all the items proposed - was run, whose fit was however not sufficient. Therefore, in order to detect those items that performed poorly we relied on the completely standardized coefficients and modification indices obtained by the software analysis. After eliminating an item of the FC construct (FC1) that was relative to the basic knowledge necessary to adopt SFT, the overall fit indices of the measurement model improved. Nonetheless, when a reliability analysis of the construct was carried out, some items still did not perform acceptably. In particular, when indicator reliability, construct variability and convergence validity were checked, all the constructs apart from the FC one and the last item of the SI construct – SI4 (namely the perception of the support received by the organizations the farmers belong to) showed good reliability. In fact, when the indicators' reliability (standardized loadings) were analyzed, only the four items relative to FC together with the item SI4, showed loadings below 0.7, commonly considered as the ideal threshold for reliability. Importantly, these 5 items considered together represent the statements which asked to respondents whether they felt equipped (with necessary knowledge and resources) and supported by organizational facilitating conditions in the decision to adopt SFT (details are provided in the questionnaire in the table 2.2, in Appendix section). For what concerns the construct reliability, the Cronbach's alpha was checked and all the constructs showed values above 0.7 (Cronbach, 1951), apart from FC which had a value equal to 0,63. Finally, when convergence criteria were analyzed, the AVE - namely the variance that is shared by the construct and its indicators - was considered. All the constructs were above the minimum acceptable value of 0.5, apart from FC that displayed a value equal to 0.37. The same applies to Composite Reliability, with all the values exceeding the minimum acceptable value (0.7) apart from FC construct with a CR=0.64.

Due to their poor reliability, the FC construct and the SI4 item were dropped. The final model therefore presents 4 latent constructs rather than 5 as shown in figure 1. The model improved its fit and all the other constructs were all reliable according to the indicators described above. As a final step, after an analysis of the modification index (MI) and the residuals (R2), also EE1 (item about the ease of interacting with SFT) was dropped, with the model improving considerably in its fit although the reliability analysis did not raise statistical problems with this item. The final measurement model shows adequate fits as shown in the tables 5 and 6.

Table 5 - Summary of fit indices for the final measurement model

Model fit indices	Recommended value (Hair et al., 2019)	Model results
Normed chi-square (CMIN/DF)	<3	2,37
Adjusted Goodness-of-Fit (AGFI)	≥0.8	0,93
Comparative Fit Index (CFI)	≥0.95	0,975
Root Mean Square of Approximation (RMSEA)	≤0.7	0,05
Standardized Root Mean Square residual	<0,1	0,038
(Tucker-Lewis Index)	≥0,90	0,967

Structural model

After assessing the measurement model, a structural model or path analysis is carried out. Firstly, the model as shown in figure 4 (the green dashed rectangular) is assessed with the exclusion of the FC construct (as it was not reliable). The measurement model results are confirmed (Table 6) and all the causal hypotheses are accepted (Table 7).

Table 6 - Final measurement model results

Item loadings, AVE, CR and alpha						
Factor	Item	Standardized Loadings	Z-value	AVE	Composite Reliability (CR)	Alpha
Performance Expectancy (PE)	useful	0.848	18.706***	0.596	0.86	0.858
	productive	0.785	17.262***			
	cost	0.748	16.361***			
	sustainable	0.708	15.392***			
Expected Effort (EE)	learn	0.847	21.208***	0.670	0.86	0.859
	use	0.764	18.511***			
	ability	0.850	21.318***			
Social Influence (SI)	colleagues	0.675	15.090***	0.555	0.78	0.780
	farmers	0.702	15.809***			
	trust	0.838	19.549***			
Intention to Use (IU)	programuse	0.947	23.582***	0.793	0.93	0.917
	intentuse	0.952	23.765***			
	alwaysuse	0.782	18.679***			

*Note: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$.*

Table 7 - Structural Model Results

Latent Variables		Hypothesis	Estimate	Z-value
Performance Expectancy (PE)	~			
	Expected Effort (EE)	H2a (✓)	0.333	5.268***
	Social Influence (SI)	H3a (✓)	0.723	9.256***
Intention to Use (IU)	~			
	Performance Expectancy (PE)	H1 (✓)	0.599	8.457***
	Expected Effort (EE)	H2 (✓)	0.215	3.538***
	Social Influence (SI)	H3 (✓)	0.270	3.451***

*Note: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$.*

As shown in table 7, PE is the strongest predictor of IU, followed by SI and EE. Importantly, hypotheses regarding PE and IU's determinants are supported by not only SEM elaborations; Indeed, through additional questions included in the survey, it was possible to enrich with more details the composition and the nature of the several attitudinal constructs.

Regarding PE, respondents have been asked to select the main reasons why they adopted/would have adopted SFT and results are shown in Fig. 5. The main adoption drivers seem to be related to a higher efficiency in farm management. According more than half of respondents (53.8%), SFT would allow to collect and elaborate more data for more informed and precise decisions. This is reflected, on the one hand, on the expectations about optimization of inputs (water, agrochemicals and fertilizers) and the consequential reduction of costs. On the other hand, the optimization of production factors would allow to increase productivity for almost 40% of who responded, while reducing overall environmental impact of the production.
When we focus on SI - the second more important determinant on IU – the key figures who might exert a social influence on farmers' decision makers might be found among those subjects considered the main sources of information regarding SFT. In the figure 6 are shown responses of participants who have been asked to indicate the most important actors sources of information regarding SFT. For what concerns the perceived utility of these technologies at farm-level, the opinions and advices of peer farmers and trusted people might play a fundamental role and in facts, producers organizations, farmers organizations, technical consultants are indicated as the most important sources. Moreover, technical salesman from input and machinery industries are also indicated as important sources of information.

Figure 5 - Drivers of adoption. Elaboration on survey data

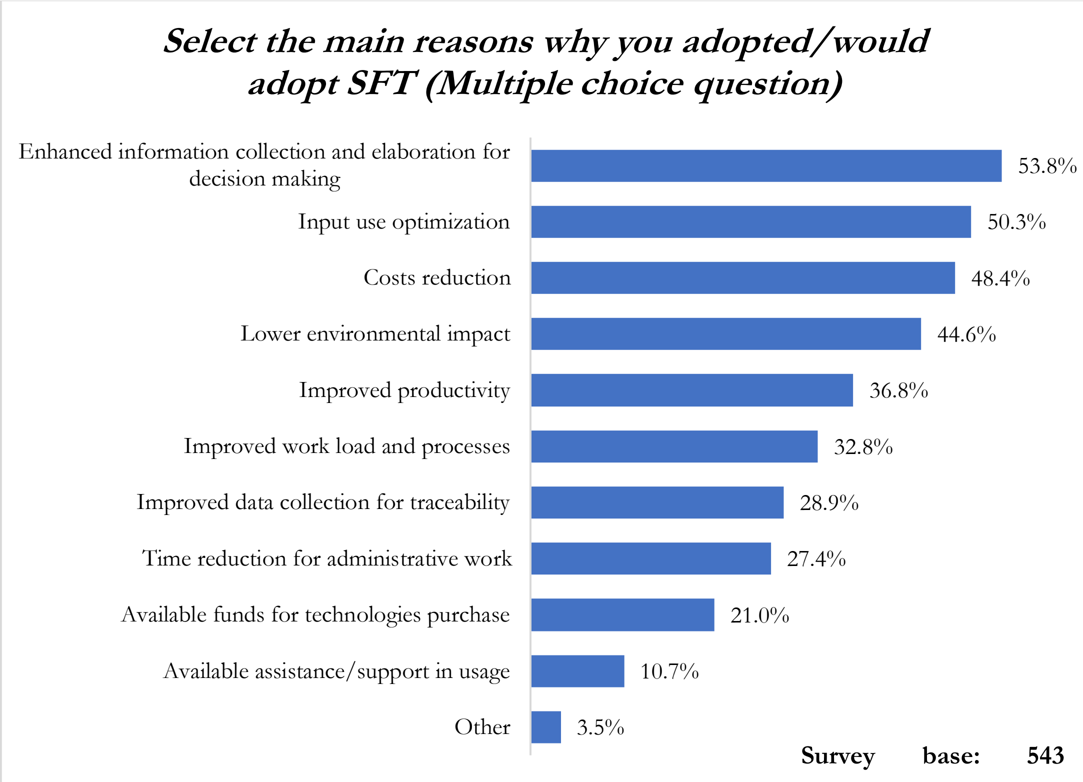
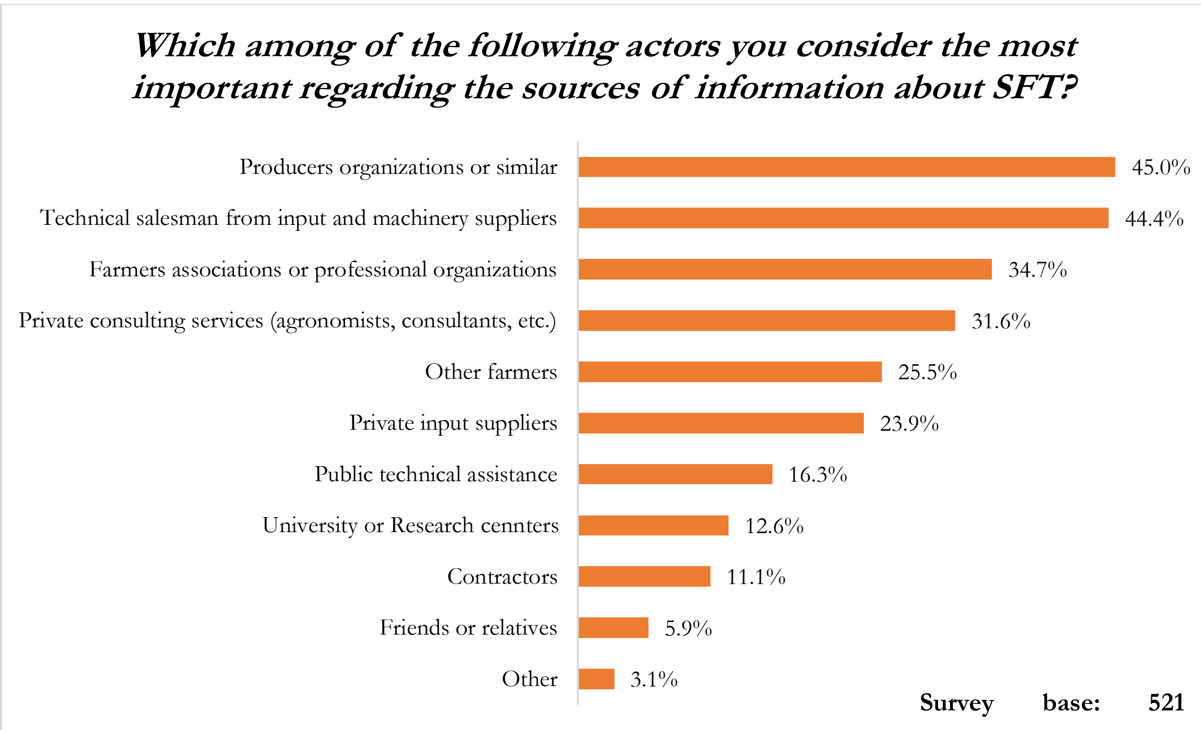
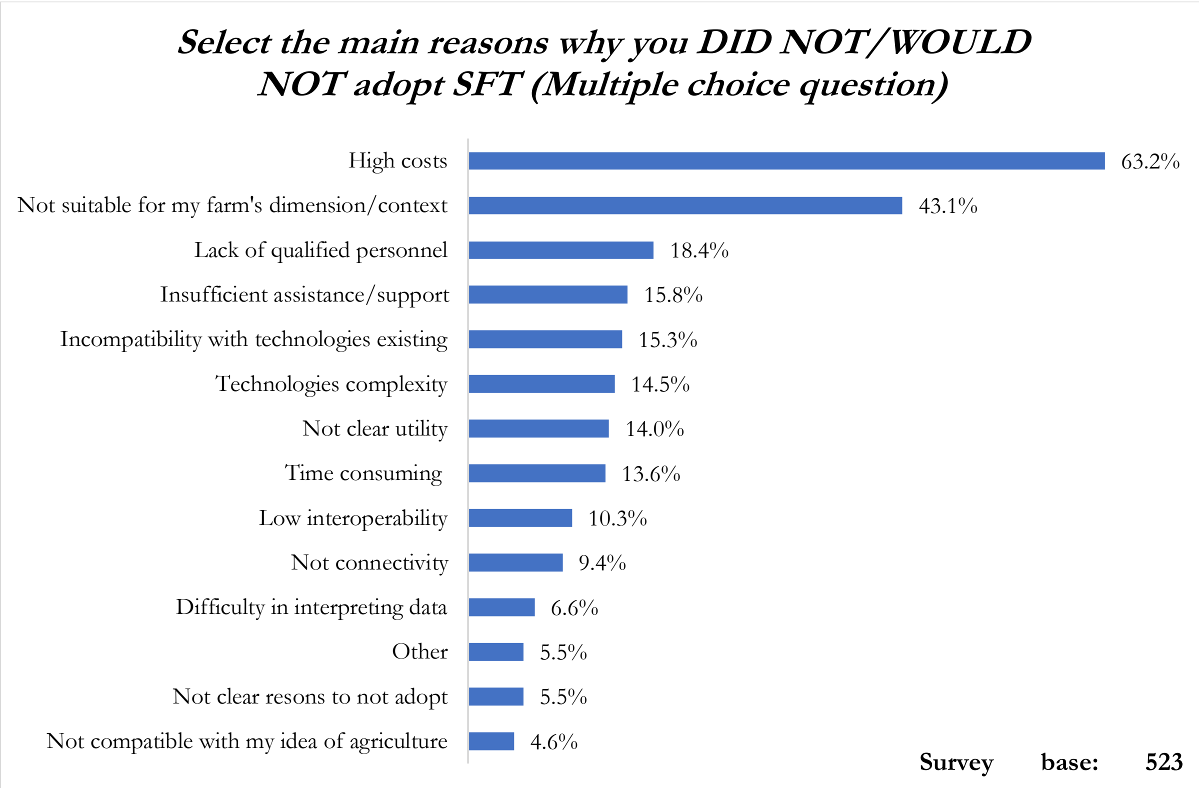


Figure 6 - Most important actors as sources of information regarding SFT. Elaboration on survey data



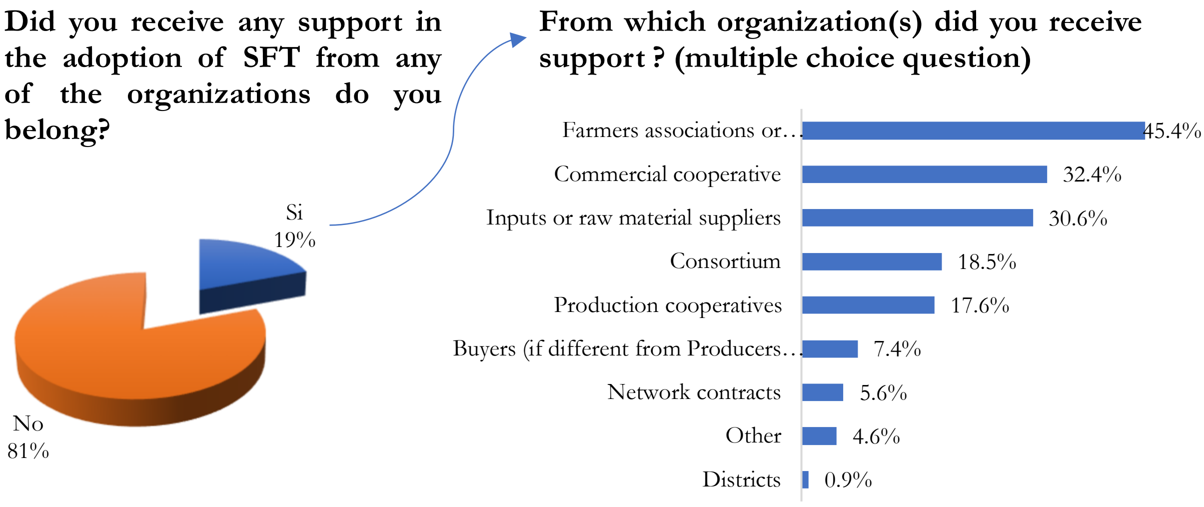
For what concerns EE construct, the fig. 7 allows to go into more details about what factors constitutes the main barriers when it comes to adopt or not to adopt SFT. In facts, when respondents are asked about main barriers to adoption (Fig. 7), technologies' complexity is not among the main one mentioned, rather being their SFT's high costs and incompatibility with dimension and operative needs of the farms. Still, 18,4% of respondents reported a lack of qualified personnel to deal with digital technologies in farms operations as main barrier to SFT uptake. Overall, when findings are interpreted as a whole, technology compatibility still appears as an important issue, especially in terms of costs structure and adaptability with certain farms typologies.

Figure 7 - Barriers to adoption. Elaboration on survey data



For what concerns the external, organizational supporting environment, as shown in previous analyses (Michels et al., 2020), the model estimated through SEM do not capture environmental and organizational facilitating conditions (being FC and SI4 not reliable). Although hypotheses 5 and 6 cannot be tested nor accepted, when these evidences are considered with additional descriptive statistics coming from the survey, they show a condition of poor organizational support perceived by respondents. In fact, as shown in Fig. 8, at the question "Did you receive support by one or more of the organizations you belong to in adopting SFTs?" more than 80% of respondents answered negatively.

Figure 8 - Support from external organizations to SFT adoption. Elaborations on survey data



Nonetheless, when the same respondents are asked from which organizations they did receive support in the adoption decision, several commercial organizations often in contact with farmers are mentioned (Fig. 8). Thus, in accordance with the study's aim to thoroughly explore the supply chain's organization effect on the overall adoption decision process (hypothesis 6.a), the following section will investigate more in detail this aspect.

Adoption decision: Zero-Inflated Poisson Regression Model

The second part of the empirical analysis deals with the actual adoption decision and results are obtained for both adopters and non-adopters.

The same covariates are regressed on both categories (see Table 8) in order to see potential differences between the two groups. In addition to farm and farmers characteristics (size, sales, age, education and arable, fruit, vegetable and viticulture sectors), the obtained latent value representing the intention to use is included in the model (IU). Moreover, the supply chain organization is accounted for and included in the model through the HI indicator introduced in section 2.2. This measure is based on several binary questions regarding the existence of formal agreements and links between farmers and other actors along the supply chain (Table 2.1, Appendix). In this way, the Hierarchical Integration (HI) indicator ranges from HI=0 (spot market transactions - loose formal link along the chain) to HI=5 (vertical integration, actors are formally linked, equity-based relationships). Before the regression analysis, multicollinearity was checked through the Variance Inflator Factors (VIF); only age was found with high VIF levels. Thus, age was transformed into a categorical variable (<45, 45-65, 65+) and multicollinearity checked again.

Regression results are shown in Table 8. For simplicity, odds ratio (exponential transformation of estimates, exp(β)) are considered for interpretation. When for a certain covariate this ratio is higher than one, then it expresses the variable's effect on the farmers' likelihood to a) not adopt SFT in the case of binary logit model (left hand side of the table 6); b) adopt multiple SFT in the case of the inflated poisson regression model (right hand side of the table 6). Thus, for what concerns logit, results should be read in the opposite direction: for non-adopters farmers, IU is the strongest, significant factor affecting positively their likelihood to intend to become adopters. Dimensional variables such as annual average sales and land use size are the others significant factors positively affecting non-adopters likelihood to intend to adopt SFT, as well as their level of hierarchical integration along the supply chain (HI significant at 5% significance level). Surprisingly, farmers' age nor education did not show any significant effect on possible adoption, as well as the specialization in any of the sectors considered. When attention moves to adopters group, results are different; farmers specialized in arable sector were more likely to adopt more than one SFT, while those specialized in fruit and vegetable sector showed a negative odds-ratio, thus lower likelihood to uptake more than one type of device. Finally, IU was the only other significant variable affecting adoption of multiple SFT.

Table 8 - Zero-Inflated Poisson regression model results

Inflation model - Logit: non adopters						Zero-inflated Poisson: adopters			
	Estimate	Odds-ratio exp (β)	Std. Error	P-value Pr(>|z|)	Hypothesis	Estimate	Odds-ratio exp (β)	Std. Error	P-value Pr(>|z|)
(Intercept)	3,059	21,306	1,765	0,083*		2,386E-01	1,269	2,3E-01	0,102
IU	-1,536	0,215	0,461	0,001***	H5(□)	1,459E-01	1,157	5,8E-02	0,001***
sales	-0,024	0,976	0,013	0,060*	H9 (□)	1,0E-04	1,000	6,3E-05	0,113
size	-0,101	0,904	0,052	0,051*	H10(□)	5,553E-04	1,001	5,5E-04	0,316
+65	-1,500	0,223	1,312	0,256	H7 (X) not supported	7,9E-02	1,082	1,9E-01	0,668
45-65	1,469	4,345	1,235	0,234		2,751E-02	1,028	1,3E-01	0,831
highersc	-0,988	0,372	1,421	0,487	H8 (X) not supported	1,179E-02	1,012	1,7E-01	0,946
degree	0,237	1,267	1,520	0,876		-4,963E-02	0,952	1,9E-01	0,790
HI	-0,889	0,411	0,381	0,046**	H6.a(□)	2,069E-02	1,021	3,9E-02	0,594
arable	-0,976	0,377	1,209	0,419	H11.a(X) not supported	2,934E-01	1,341	1,3E-01	0,024**
fruitveg	-1,352	0,259	1,160	0,244	H11.b(X) not supported	-2,8E-01	0,756	1,6E-01	0,094*
viticult	-0,500	0,607	1,127	0,659	H11.c(X) not supported	-8,727E-02	0,916	1,6E-01	0,600

Note: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$.

3.5. Discussion

The first research question assessed in our study, i.e. "*Which are the main factors affecting the intention to use SFT?*" (RQ1), disclosed two main interesting results.

As a first result, farmers show stronger intention to adopt SFT that in their opinion (i) will deliver higher productivity, cost efficiency and sustainability performances, (ii) that are easy to use and (iii) whose use is supported by their social environment (trusted people, colleagues and other farmers). Most of the tested hypotheses are in fact supported by our model (Table 7): expectations about technologies (PE) are the most important drivers of intention to use, as previously found by several scholars (Faridi et al., 2020; Michels et al., 2019; Venkatesh et al., 2003) and confirmed by descriptive statistics shown in previous section. Differently by Michels et al. (2019) though, the social influence around farmers (SI) seems to have a stronger impact than the perceived technologies' ease of use (EE) on both the expectations about SFT' performances and the intention to use them. Especially for what concerns the perceived utility of these technologies at farm-level, the opinions and advices of peer farmers and trusted people might play a fundamental role. At the same time, EE's lower effect might be due to the technologically advanced nature of the online sample, probably more facilitated than the average with digital technologies. Moreover, technologies' complexity or ease of use might not be the central issue when looking at expectations about SFT – as confirmed by data shown in Fig. 7.

As a second result stemming from RQ1, farmers seem to consider the organizational environment in which they (and their farms) are embedded as not facilitating the adoption of SFT. Although the facilitating conditions (FC) construct is not statistically reliable enough to be considered as a latent variable to test our fourth hypothesis (namely, that FC positively affects the SFT adoption decision), relying on the organizational support construct (item SI4)) and descriptive statistics instead still indicates that the majority of respondents do not perceive that the organizations surrounding them were of any support in the process of deciding over the adoption of SFT. This evidence seems in conflict with several recent studies which highlight the important role played by numerous actors that are actively participating to the digital agriculture innovations systems - such as advisors, tech providers, professional associations etc. (Charatsari et al., 2020; Kernecker et al., 2021; Klerkx et al., 2019). Nevertheless, our results suggest that farmers seem to poorly perceive external support in the phase of knowledge/use intention, proving that the adoption process in these phases is still more individually driven.

As far as the second research question addressed in our study is concerned, i.e. "*Which are the main factors affecting actual decision to adopt SFT?"* (RQ2), additional useful insights on the adoption determinants are provided. Firstly, it is interesting to notice that all the variables related to the farms' size are significant and positively affect the non-adopters' adoption decision, while no effect is observed for the adopters (Table 8). Such evidence appears reasonable: while for non-adopters size (both in economic and land disposal terms) might be a decisive, necessary condition to intend to adopt SFT, for adopters who already use SFT and strive to integrate multiple technologies, financial resources and land disposal might not be discriminant conditions. Instead, IU seems to positively affects the adoption of more SFT, supporting the evidence that at this degree of farm's technological uptake, individual attitudes and intention seem to be crucial factors.

Secondly, our analyses indicate interesting differences between the non-adopters and the adopters also with regards to their sector of activity. On the one hand, when the logistic function is considered, no sectorial specialization seemed positively associated with possible adoption of those not yet adopting these technological innovations. On the other hand, when looking at the adopters by means of the poisson regression model, the F&V and arable sectors have different, opposing effects; the specialization in the F&V sector seemed to affect negatively farmers' adoption of more SFT. That might be explained with the current lower availability of specific SFT for the F&V sector (Kernecker et al., 2020). Indeed, when descriptive statistics are analyzed, it can be noticed that very few farmers from this sector declared to have adopted more than one technology. In general, farm management information systems (FMIS) are the most common for these farms types, as the adoption of a logbook for pest treatment management is required at national level. When the specialization in arable sector is considered, it showed instead a significant positive effect on the uptake of multiple SFT. This result is in line with previous findings and seems to confirm the hypothesis that a higher compatibility of SFT is found with bigger, arable farms (Shang et al., 2021); on average, arable farmers benefit from the integrated usage of several SFT, as GPS-based devices and similar variable rate technologies (VRT) as well as FMIS and sensor-based technologies.

Further interesting results concern the influence of farmers' characteristics on SFT adoption. In fact, both age and education levels are found not statistically significant among both adopters and non-adopters. On the one hand, these results are in line with some findings of recent literature that confirms that being "young and educated" seems not to be a determinant for digital technologies' adoption at farm level (Pivoto et al., 2019; Shang et al., 2021). On the other hand, the nature of the sample - composed mainly by younger and more educated farmers than the national average - might have further downsized these sociodemographic effects.

Finally, when the focus is on supply chain organization, our elaborations showed that on average, farms' integration along the supply chain is associated with a higher intention to adopt SFT, although such formal integration do not explain adoption of more SFTs. Moreover, when various formal links are considered separately, farmers receiving support and resources by commercial partners (e.g. cooperative, consortium or similar producers' organizations) are more likely to intend to adopt SFT (odds-ratio less than one). This evidence contributes to recent studies that report how agricultural digitalization might be associated with supply chain hierarchical integration (Pesce et al., 2019). From an infrastructural perspective, vertically integrated supply chain might more likely imply an integer, whole data chain which favors information flow. From governance perspective, to deal with data ownership and privacy issues, it might be fundamental for farmers to be able to rely on specific support figures. Generally, such favorable conditions are more likely to be available in a context of hierarchically integrated supply chain.

3.6. Implications and Conclusions

The study contained in this chapter has several implications for different agri-food systems' stakeholders. To the best of author' knowledge only a few contributions thus far have investigated the adoption of SFT through a comprehensive and exhaustive analysis of its determinants along the whole decision process, namely from the intention to adopt to the actual adoption. While the literature so far has looked at SFT adoption as the result of a simple binary (i.e. yes or no) decision, this study considers attitudes and intentions towards the use of technologies as the antecedents to the decision to adopt or not to adopt. By means of such an extended conceptual model, this study allows to analyze and consider additional potential determinants of the adoption, such as the organizational conditions.

In terms of theoretical implications, the results concerning the intention to adopt show that the usefulness of digital technologies needs to be clear to their potential users and that the social environment around farmers is key, more than the effort needed to use these technologies. For what concerns the first aspect, farmers convinced about the SFT usefulness in terms of higher productivity, cost efficiency and improved environmental sustainability show stronger intention to use and are more likely to finally adopt. Looking more specifically at items behind the latent variables, it is possible to note that productivity aspects seem to be more important than sustainability when it comes to the expectations about technologies' performances - PE. In light of recent policies that indicated the digital technologies as important tools for sustainable intensification of agricultural production (European Commission, 2020), attention must be paid to guarantee that this *digitalization* process will properly cover both the efficiency and sustainability aspects of such important challenge. A second important implication can be grasped when looking more specifically at the influence the society at large exerts on the farmers decision makers: people that farmers trust seem to play a crucial effect, stronger than peer farmers and other colleagues. Finally, when looking at current adoption dynamics, findings show that highly motivated farmers, with bigger farms and higher levels of vertical coordination along the supply chain, are more likely to adopt SFT.

These results have also practical implications for various stakeholders in the agri-food system. First of all, this study addresses policy makers who support farmers and other stakeholders (e.g contractors, agronomists, agricultural workers) in joining the digitalization process. Given the fragmented structure of the agricultural sector both in Italy and Europe, it is important that economic, training and support measures will be implemented to guarantee access to these technologies to small and medium farms, in order to avoid the risk of increasing the digital divide at the farm-level.

This study offers interesting insights also for other stakeholders that might play an important role in facilitating the diffusion process of digital technologies along the supply chain. More specifically, this chapter reveals that farmers perceive the organizational facilitating conditions as not supportive of their whole decision process. Actors operating at the supply-chain meso-level (e.g. producers' organizations, districts, farmers associations and similar) might be fundamental not only in supporting the adoption process, but also in the implementation and data management phases where trust becomes key to the adoption (Giagnocavo et al., 2017; Wolfert et al., 2017). The same applies to other industry actors (retailers, processors, etc.) that might have the potential to drive the future of the value chain digitalization. All these actors might find interesting insights on the possibility to guide a digitalization process that is currently mainly individual, thus disempowered. Furthermore, these readers might find useful suggestions on how to set a proper digitalization strategy from the farm level, by focusing on key adoption and diffusion determinants. Finally, these results might be of interest for technological providers and public/private support services, who might find useful insights regarding the key role of specific actors and technological attributes influencing the adoption and use of digital technologies.

Conclusions

The study comprehensively investigates the adoption of SFT in Italy. In order to analyze the multistep and multifaceted adoption decision process, different methodologies are used to analyze both the determinants of the intention to use and of the actual adoption. Various typologies of determinants are considered (behavioral, technological, relative to farms and farmers' characteristics), with a particular focus on the role the organizational environment around decision makers. To this aim, first the intention to use SFT is analyzed; on the one hand, our results highlight the key role the social environment around decision makers, as well as the technological features of SFT in terms of usability and performance expectancies, play in the adoption process. On the other hand, variables related to infrastructural/organization support perform poorly, indicating no average effect on the intention to use. Moreover, with the aim to further explore the role of organizational factors, the actual adoption decision is analyzed. In this case, in addition to the intention to use, farms' and farmers' characteristics are considered, as well as different variables measuring the level of farms' formal commercial integration along the supply chain. When looking at non-adopters, findings highlight that on average, larger farms, more integrated along the supply chain, are more likely to intend to adopt SFT, while both age and education are not statistically significant. When instead the focus moves to the adopters, only the users' intention to use seem to clearly, positively affect the final adoption decision.

Overall, this study partially confirm the key role that organized commercial networks can play as adoption drivers along the supply chain. In addition, it indicates that the current SFT adoption process relies more on individual intentions, resources and existing formal relations along the supply chain. On the one hand, these findings highlight a consequential existing risk of digital divide for farmers and farms that might not be able to satisfy these requisites. On the other hand, they identify some important aspects that various stakeholders might consider to optimally support farmers in such digital transition, with particular reference to the role of social, organizational as well as technological factors in the moment of attitudes formation. Finally, the study highlights the great potentialities of SFT for farms showing high levels of commercial integration along supply chains, in terms of superior traceability, coordination and value distribution.

Chapter 4

4. Diffusion of digital innovations in the Italian agriculture: socio ethical perspectives with a RRI approach

4.1. Introduction

The process of digitalization of agriculture is nowadays a reality. As highlighted by previous chapters, digital technologies' diffusion dynamics might vary considerably depending on various aspects such as adoption rates, ad-hoc policies, stakeholders' interest and support in the overall diffusion process. That withstanding, it is now a fact that this wide range of technologies available are able to concretely contribute to make agricultural production more efficient, by considerably reducing the use of inputs and thus production costs, together with optimized production output in terms of quality and quantity (Basso and Antle, 2020; Fabregas et al., 2019). Supported by these evidences, several scholars allege that, in line with the ongoing transition towards more sustainable agrifood system, digital technologies in agriculture can lead the sector in the direction of a sustainable intensification - SI (Finger et al., 2019; Klerkx et al., 2019). In facts, great expectations in this direction have also been expressed from leading institutions such as FAO, World Bank and OECD (Trendov et al., 2019; Tripoli and Schmidhuber, 2018; UN Compact Global and PA Consulting, 2017). At the same time, the industry of agriculture 4.0 expresses optimism with yearly increasing market value worldwide (Osservatorio Smart Agrifood, 2021), reaching real hype moments on the market see Klerkx and Rose, 2020.

On the other side in respect of this general enthusiasm, few scholars researched how such radical innovation, followed by the *Schumpeterian* "creative destruction" - disruptive effect, might impact on socio-ethical aspects of the society, with unexpected and unintended consequences. Indeed, by involving both ecological and social systems, agricultural practices often imply and stimulate several debates concerning socio-ethical issues on different topics (Kritikos, 2017). Nonetheless, when compared to the vast literature that since the nineties explored and studied the technological development and the diffusion of these technologies in agrifood systems, the contributions which used a forward-looking approach to anticipate potential effects on the society represents still the minority. Kritikos (2017) in a report presented to the STOA panel of the European Parliament, lists and discusses several socio-ethical issues related to the diffusion of precision agriculture in Europe, saying that "there is a need to address the question of the balance between the cost of introducing the technology versus the expected benefits for the farmers and biodiversity" (pp.44). Van der Burg et al., 2019, in a recent review on ethical issues arose from digitalization of the sector, identified three main "*ethical challenges*", namely data ownership and access, distribution of power and impacts on human life and society, calling for a responsible research and innovation approach. Bronson (2018), adds on this by underlying the need to include right holders "historically marginalized in innovation decision processes" (pp. 10) to promote an inclusive discussion on the direction of the smart farming innovation paradigm that, according to the author, reflects a technologist-productivist approach typical of the intensive production (see Wolf and Wood, 1997). In line with this comment, Rose and Chilvers (2018) critic the possibility to achieve a SI with the current development of digital technologies in agriculture, saying that "Despite the potential benefits of a new technology revolution, the dominant techno-centric narratives associated with smart farming should be treated with caution" (pp 2-3). More in detail, Rose et al. (2021) underline how the current debate on SI has widely failed to give sufficient emphasis to social sustainability, identified in the study as the effects on *people* populating the food system, more accurately in the agricultural production. Although these studies explores different socio-ethical aspects related to the diffusion of different digital technologies, several authors among the one cited point out the need for a comprehensive approach to these socio-ethical issues (Bronson, 2019; van der Burg et al., 2019; Klerkx et al., 2019; Klerkx and Rose, 2020). Rose et al. (2021) themselves propose an operationalization of the Responsible Research and Innovation - RRI framework to define a "responsible sustainable intensification" so that the process of digitalization of agriculture can work "for people, production and the planet" (pp. 2), together. In a more recently published work, some of the same Authors advance another proposal for the application of the RRI framework to the study of the responsible development of the robotics in agriculture (Rose, Lyon, et al., 2021).

In this work, the analysis from these debates and discussions to explore some socio-ethical issues might emerge as a consequence of the diffusion of digital technologies in Italian agriculture. More in detail, the RRI approach recommended from previous literature is followed, with the aim to identify opportunities, risks, social effects and possible interventions that might shape the (socially sustainable) diffusion of these technologies in the Italian context. In the following sections, first a brief state of the art on this topic is presented and discussed, and research questions precisely stated. Then methodology and a description of data used are described. To conclude results are presented and discussed, also in relation with results obtained from previous studies.

4.2. State of the art

Responsible Research and Innovation (RRI) and agri-food applications

Most of the references related to RRI refer to the highly cited paper "Developing a framework for responsible innovation" by Jack Stilgoe, Richard Owen and Phil Macnaghten (Stilgoe et al., 2013). In this work, authors recall the concept of *responsible innovation* and introduce a framework to articulate this approach, to move "from the governance of risk to governance of innovation itself (Felt et al., 2007)" (pp. 1570). In explaining the need for this transition, Stilgoe et al. review the evolution of the concept of governance of science and technology. They start with the description of the limiting *consequentialist* model of responsibility, which is based on retrospective approaches to innovation's impacts and risk-based regulations and showed limited capacity "to identify in advance most of the profound impacts (…) experienced through innovation". Dissatisfaction with these risk-based approaches led researchers' attention to new forms of innovation governance, able to take a forward-looking view of science and technology responsibility. This new view allowed to open up scientific governance to new inputs and, moreover, to interpret innovation responsibility as a collective concept which needs to be shared among different actors of the scientific system. Responsible innovation is defined by Authors as the process of "taking care of the future through collective stewardship of science and innovation in the present." (pp. 1570) and several different conceptualizations have been proposed (Von Schomberg, 2013; Wickson and Carew, 2014). In a recent contribution, Eastwood et al. (2019) report the mostly used RRI frameworks including the anticipation-inclusion-reflexivity-responsiveness (AIRR), the RRI tool proposed by European Union (Groves, 2017) and the five RRI keys framework by (Ravn et al., 2015).

In the agri-food sector, RRI approach has been limitedly applied so far (Blok et al., 2018), although several authors recognize both the need and the potential to use it in such specific and crucial human activity (Gremmen et al., 2019). The main areas of applications regard animal welfare, agricultural genetic modification, agriculture, food and environmental ethics in general, but also topics more aligned with traditional Research and Innovation objectives, such as competitive advantage, market orientation and profit maximization (Blok et al., 2015; Lees and Lees, 2018; Macnaghten, 2016; Purwins and Schulze-Ehlers, 2018).

Recently several authors called for an application of RRI approach to the last wave of radical innovation that is affecting agriculture, the use of digital technologies to the whole agri-food supply chain (Bronson, 2018; Bronson and Knezevic, 2016; van der Burg et al., 2019; Klerkx and Rose, 2020; Regan, 2019; Rose, Lyon, et al., 2021). So far most of the studies that researched the socio-ethical aspects of digital technologies' diffusion referred to technologies used at farm level, such as precision agriculture and smart farming (Klerkx et al., 2019). Fleming et al. (2018) conducted a discourse analysis on semi-structured interviews with different stakeholders of the Australian grains industry. Findings reveal that there are different visions on the use, access and effects of big data in farming, with some preliminary evidence of beneficial effects mostly for "big farming". Moreover, Authors identified key issues to be addressed in further development of digital technology, namely trust, equity, distribution of benefits and access. Trust issue has been investigated by Wiseman et al. (2019), in relation to the farmers' reluctance to share their agricultural data with other actors, still in the Australian context. In this study, farmers' lack of trust is analyzed with reference to legal and regulatory frameworks and findings revealed how farmers' concerns were related to several issues such as lack of transparency about the terms of use in data licenses, ownership of data, privacy, inequality of bargaining power, etc. According to the Authors, all these matters should be addressed by opening up and making more transparent governance frameworks implemented by agricultural innovation industries. The recent contribution by Rose and Chilvers (2018) is aligned with this view and, referring to the concept of inclusion of various societal actors in the debate around smart agriculture technologies, calls for the application of the RRI approach as found in Bronson, 2019 and Eastwood et al., 2019. In details, Kelly Bronson refers to RRI to investigate the social and ethical dimensions of big data, by focusing on the normative aspects of the technical decisions of some actors "shaping innovation", such as engineers and smart agriculture designers. Findings revealed how these actors working to "shape" these innovations "hold a narrow set of values about good farmer, farming and good technology and their data practices privilege large- scale and commodity crop farmers." (pp.5). Eastwood et al. follow the same approach to assess smart dairying development in New Zealand. Authors developed a scheme of RRI indicators through which were able to identify socio-ethical challenges addressed by innovations shapers and some other gaps to deal with. In this respect, the authors underline how to efficiently embed and merge RRI principles with R&D activities a comprehensive approach is needed. Without such setting, a fragmented approach might be implemented with the risk of "overlooking some RRI principles and having RRI as an add-on rather than a core feature of research and innovation" (Eastwood et al., 2019, pp. 762). Finally, in a recent article, Brier et al. (2020) follow the operationalization of RRI approach proposed by previous literature to foresight potential implications associated with the diffusion of virtual fencing in pasture-grazed cattle farming. These authors used a Delphi approach to identify main benefits and barriers associated with the diffusion of these technologies. On the one hand, their findings revealed the need for further fore-sighting activities to anticipate possible positive and negative implications of virtual fencing (e.g. studies of public perceptions). On the other hand, the results obtained are addressed to technology developers in order to suggest areas to focus on in the R&D process, by giving guidance in the process of making virtual fencing more ethically acceptable.

Research objectives

In line with the approach of Brier at al. and with the call for more evidences for RRI applications on this topic, this study adopts a responsible innovation approach to foresight socio-ethical implications of Smart Farming diffusion in the Italian context. The Anticipation-Inclusion-Reflexivity-Responsiveness (AIRR) framework was chosen among the several ones available, for its simplicity, clarity and diffusion in the previous literature (Eastwood et al., 2019). More precisely, the present study has a double aim reflected in the following research questions:

1. To identify and anticipate main opportunities and risks associated with the diffusion of smart farming technologies in the agricultural sector;
2. To outline and propose measures of different nature and finality to favor a socially sustainable process of digitalization of Italian agriculture;

The following section describes the methodological approach used and its implementation. Moreover, it reports the sample structure and the type of analyses carried out.

4.3. Methods and sample

In line with the forward-looking approach chosen, this study implements a Delphi approach to favor the inclusion of different actors in the anticipation exercises and to foster exchange of the different positions emerged. The Delphi method originated by its use in RAND Corporation in 1950-60's (Dalkey and Helmer, 1963), to improve (military) technology forecasting. Its use is recommended when there is not a definitive method to conduct a research, neither empirical data nor statistical support for valid forecasts (Okoli and Pawlowski, 2004; Schmidt, 1997). It consists in a set of successive structured "communication process"- usually in forms of questionnaires to a panel of experts - using feedback to refine an informed perspective on complex or uncertain issues (Padel and Midmore, 2005). The Delphi method has been extensively used in agrifood economics and management research (Holt et al., 2007; Kline et al., 2016; Luo et al., 2017; Padel and Midmore, 2005). Among the topics researched through this methodology, there is also digital innovation's diffusion in the agricultural sector (Aldrighetti et al., 2021; Busse et al., 2014; Luthra et al., 2017) and, recently, the same method has been used to anticipate uses of technologies and social changes (Brady, 2015; Brier et al., 2020; Eastwood and Rue, 2017).

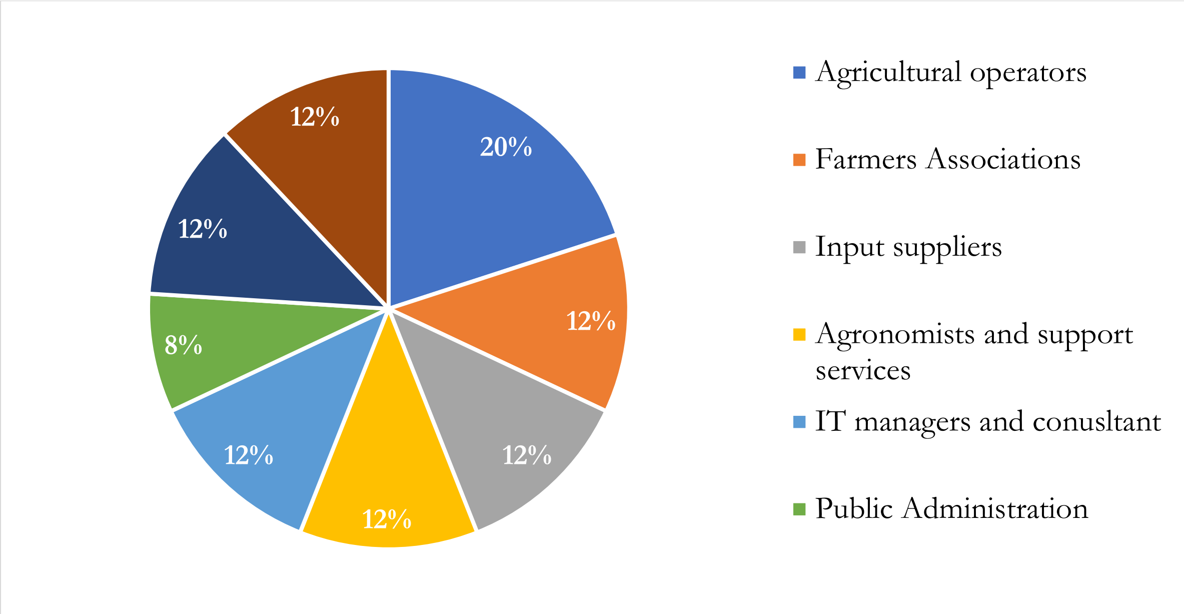
According to Shon and Swatman (1998) the main steps involved in designing a Delphi study involve: identifying, contacting and recruiting participants, designing and circulating the first-round questionnaire, producing feedback from the first round, designing and circulating the second-round questionnaire, analyzing the results of the second round and preparing a final presentation.

The first round is generally more exploratory to make emerge initial concepts and it takes the form of open-ended interviews. This is often followed by one or more processes of classification/taxonomy, that aims at reaching a synthesis of the various positions emerged. In this study a two-step procedure is followed and over a three months period, with a moment of anonymous exchange and feedback in between, through a report which synthetized the material collected (Adler and Ziglio, 1996; Ilbery et al., 2004). The selection procedure for the panel of experts is a key process that was carried out referring to previous established schemes (Aldrighetti et al., 2021; Markou et al., 2020; Rowe et al., 1991). As suggested by Millar et al. (2007), the author set some inclusion criteria that regarded: the involvement and the knowledge of the topic investigated; the motivation and the willingness to participate to the Delphi process; the interest in participating to the aggregation process of judgements, as a way to accede information difficult to reach otherwise; the inclusion of a sufficiently diverse range of subjects, according to the competencies and the value commitments. This last criteria acquires particular importance in light of the responsible innovation approach we used here, since it represents one of the main pillar of the RRI framework and "a drive to invite all relevant actors into inclusive fora and collectives to socially shape specific projects or innovations" (Rose and Chilvers, 2018, pp. 4).

The sample was made up through both a-priori and snowball sampling. On the one hand, the author referred to several categories from the whole agricultural system previously identified (e.g. as in Busse at al., 2014) as the following: farmers, producers' organization, farmers' associations, agronomists and support services, business and IT consultants, different input suppliers (seeds, agrochemical and machinery industries), public administration, university and public/private research. On the other hand, participants were asked to propose other possible stakeholders that would fit the inclusion criteria described before. 30 actors were finally invited to participate. A description of the study with the aims of the research, the methodology adopted and the program for the following activities in which they would have been involved was set to all the participants.

From this initial group, 25 experts accepted to participate to the study. The sample dimension is in line with other studies as found in Okoli and Pawlowski (2004) (Figure 10).

Figure 9 - Composition of the panel of experts



First round

The first explorative round started in May 2021 and consisted in 10 open questions distributed among the 4 sections from the AIRR framework. Each interview lasted from 40 to 120 mins. The interviews were recorded and coded with reference to the respective AIRR sections, the Nvivo software was used to carry out the directed content analysis, by facilitating data collection and objective analysis. The emerging concepts were refined and summarized under umbrella codes. Before the second round started, a summarizing report including the first analysis was sent to all participants.

Second round

The second round took the form of a survey, accessible on-line from August to September 2021. The survey was composed by 13 Likert-scale questions similar in the content to the ones in the first round, with one additional section regarding the role of the public bodies in the SF diffusion process. Pre-definite responses were defined starting from the codes obtained in the open interviews and 18 responses were finally collected, with a decreased rate in participation in line with previous studies (Aldrighetti et al., 2021; Kline et al., 2016; Su and Canavari, 2018). The analysis of the survey is based on descriptive statistics such as means, median, mode values to rank emerging concepts, together with inter-quartile measurements to explore possible consensus as found in (Beiderbeck et al., 2021; Ilbery et al., 2004; Shon and Swatman, 1998). Finally, a summarizing report with final analyses was sent to all participants.

4.4. Findings

First round

a) Anticipation

The interviews started asking participants the definition of Smart Farming technologies, to understand what the general, initial ideas behind this concept were. The first emerging definition, which found agreement among respondents, is that of a set of digital tools able to collect and elaborate agricultural data, with the aim to improve decision making in farms management (Table 9). The following most common responses among experts, shows a certain level of confusion about the different definitions given to this group of technologies (e.g. "digital agriculture", "agriculture 4.0", "precision or smart farming") and the general idea that is not possible to give a unique definition to this process of innovation, since it might vary considerably depending on the contexts of application. One interviewed said:

"Today there is not a unique definition, or at least I don't know it, about Smart or Precision Farming in cultivations or livestock, if there is a minimum set of technologies to say "you're doing precision Farming". There is a lot of emphasis on labels –Agriculture 4.0, 5.0, etcetera, on the communication and the diffusion of some technologies also by some legislative incentives (such as Industry 4.0). Not enough on the actual use of data, on the real utility of digital technologies"

When it comes to benefits and risks due to the diffusion of SF, on average respondents reached initial higher consensus. Regarding the main benefits, the most coded one regarded the possibility to obtain higher efficiency in farms management.

"I think that in respect to the past, with digital technologies we have the possibility to valorise scientifically a large quantity of data and information that might be useful to the farmer to understand the state of the art of its farm, to plan its operations on the field but also to better understand the current situation, to plan investments about new products or innovations".

Several respondents referred to a better management of complexity deriving from the farm, thanks to more data suitable for informed decisions. Others reported about an improved optimization of classic production factors such as land, water, agrochemicals, thus a cost reduction – the third most cited benefit. The following extraction summarizes all these benefits:

"You get a reduction on the use of productive inputs and an optimization of outputs. If we want to use one word, I would say "efficiency". (…) Depending on where it is used for example, we demonstrated that by combining

agronomic techniques – thus knowledge, agronomic knowhow and digital technologies – it is possible to obtain an increase in productivity of +600% in respect to the average, with a water consumption reduced of 50%".

When it comes to main risks, respondents seem to be even more aligned; the main risk perceived is by far the situation of digital divide because of an unequal access to digital technologies by all actors. Behind this unequal access there are multiple barriers that might be perceived differently according to the actors involved: infrastructural, technological, cost-related, demographical. The following statement by a respondent summarizes it well:

"The access to technologies might be a multidimensional theme, where you must have the availability of technologies, the awareness about the possibility that these tools might help you to do something better for your job, for your life. And you must have physical access to this technology, there must be connectivity, these technologies must be financially accessible - you should be able to buy them and to use it. And then… Then it should exist awareness about the use you imagine, according to your agenda of development, it might a personal or community agenda. And clearly we are in the situation where.. yes, there is an high risk that there is a discrepancy between people that can accede to these technologies from a financial point of view and those who cannot. Without considering the problems due to the broadband coverage that still exists haphazardly – this is the minor issue (…) – the main issue is that technologies are typically adopted by those who are in dominant position in the society and this happens in every society in its transpositions. Therefore, where technologies enter the society, there is always the risk that someone acquires a comparative advantage. Thus, the risk is that who has less possibilities to adopt might lag behind."

Barriers to adoption involve also the second more cited code in table 9 which regard the misalignment between technological offer and demand from users. In this respect, respondents underline how this incompatibility might be due to several different factors: the technologies' design, the complexity, the functionalities not adapted to agricultural uses, the business model of technology providers (product-based vs service-based).

The third most cited risk is also one of the most complex phenomenon that might derive from SFT diffusion: the risk of informative oligopoly/monopoly and imperfect competition. This situation may occur in the case few actors detain most of data, thus information and informative power, that in turn becomes market power. These actors might be different in nature, although the subject that currently are able to set "closed" digital environments, to collect and elaborate data are fundamentally of two types: digital technology providers (large and small start-ups) and the input industry (especially agrochemicals and machinery). These actors are already offering on the market digital services mostly in form of platform/apps or similar digital environments, that are able to host different types of agricultural data collected on farms, to elaborate them to give information for decision-making. Several experts underlined how most of these digital environments are "closed" in the sense that they are not able to collect and elaborate all type of data formats, since there is not a common, open data standard. This situation might lead to two main consequences; on the one hand, a user who decides to adopt one of these technologies and thus to collect, elaborate and share its agricultural data with the technology provider, might find himself in a situation of "technological lock-in" whether it might want to change "digital ecosystem" for its services. This because of the potential technological/legal barrier to move stored data from a system to another one or to make communicate two different technologies, a situation of "interoperability". On the other hand, the agricultural data accumulation from few actors might lead to a situation of oligopoly/monopoly with consequential risk of market manipulation. This might be especially problematic in the case of large companies who offers integrated services, from agricultural input (e.g. seeds, pesticides) to digital devices, algorithms for data-analyses and recommendations to farmers on agricultural products purchasing. In these cases, these recommendations offered to farmers on the basis of analyses on data collected might lead to price discrimination by input suppliers.

"This amount of data accumulated by these players had precisely the purpose of creating big data. For example, for the construction of automatic guided machines. You know, an automatic guided car needs, has a dialogue via the network and therefore the… let's say, farmers' decisions are made according to a series of information that, who gets them from? The manufacturer gives them to him! Now if the manufacturer, after you have automated it your company tells you: "look, you have this information because you pay this for a subscription. From tomorrow and double the cost". It is not that you have many roads having done all the investment with that technology in order to be autonomous: there is no freedom. So here the central theme is the freedom of enterprise or self-determination of enterprises, which in my opinion is running a strong risk, when you tie your hands and feet to a technology supplier."

"And then there's the data problem. The data that is collected at an aggregate level begins to be many. There are some of the world's leading companies that basically try to get people to work, the farmers – now I speak mostly about precision farming – inside their own environment. For which operator, driving machine, operator and processing all created inside of your environment. So I can have the data, let's say, of the sowing operations collected. On large extensions for large periods. This thing allows me to do some modelling forecast. If I have large-scale forecasting modelling, I can go second me even playing no? On the stock exchange on futures I don't know about corn or soybean production, etc. these are extremely powerful information."

The last question regarding the anticipation section is a forward-looking exercise to anticipate the potential effects of the diffusion of SF in the society, on a 30-year time horizon. The most probable scenario according to the participants was that of a more modern agriculture, with younger and professional farmers heading fewer larger farms, depending less from labour force. In this context, the digital technologies will increasingly diffuse among agricultural society and this technological support will be crucial to remain competitive. This transformation will be accompanied from an automatization of the processes, with an increasing use of robots on-farm; indeed, the agriculture's "automatization" is seen as the second most probable scenario. Both these projections are summarized in the following answers by one of the experts:

"I think a lot of processes we are seeing now will be completely digitalized. It won't make any more sense to occupy people to do certain things: I'm talking considering a 30-year scenario… For sure we will have a lot of automated guided machines, which will be completely automatized. It means that there will be larger fields, it will change the land structure of our country and probably of some other parts of the world".

The third most nominated scenario according to the experts is also the more optimistic: here Smart Farming technologies are thought to support a sustainable intensification of agriculture, through a more precise and thus efficient management of agricultural processes, with a reduced, optimized use of any inputs and an improved agricultural productivity.

"In 2050, I think these processes will be faster than in the past, but not that fast, especially in an agriculture like the Italian one, so fragmented and so on. But the agriculture of tomorrow in Italy – I am not saying in other parts of the world – it will always be agriculture more supported by digitization. Yes, and with an eye to everything which is the environment, that is the environment and everything that does intersect with agricultural activity will become increasingly important in Italy, in Europe we already see this from EU policies."

b) Inclusion

This section invite participants to think about how a phenomenon might impact the society and how the various stakeholders may be impacted or react to innovation (Rose, Lyon, et al., 2021; Sandra Schillo and M. Robinson, 2017). In this case, experts were asked to elaborate on potential impacts that digitalization of agriculture might have on actors involved in this on-going process. Following the call to foster inclusion in RRI applications to this topic, authors started by inviting participants to consider all actors, both traditional and newcomers brought by the digital innovation wave, which might be involved. Then, respondents were asked to list the actors who might benefit/risk more as a result of an increasing diffusion of SF.

For what concerns the possible beneficiaries, the majority indicated the technology providers as the potential winners. In the experts' opinion, this category of actors might include different figures, from the high-tech giants active in other industries to the flexible, innovative start-ups delivering specific digital services to farms. In both cases, the experts seem to expect the arrival of

some disruptive actors from this group able to capture most of the value created from the digitalization of agricultural sector.
Agricultural operators were also considered among the actors who more likely might benefit from the diffusion of SFT, although not all of them. In general, as already anticipated by the digital divide risk description, younger, more educated operators open to innovation, working on larger, professional farms and were thought to benefit the most.

"So in my opinion the problem is this, the problem is that even here the demographic variable will play a fundamental role, in the sense that I am convinced that the youth component is better prepared, let's say, to adopt these solutions. But the point is also another, very often to work on global, European, modern competitive supply chains you have to interface with subjects who are non-agricultural: processors, transporters, distributors. And there is the increasing need for certification and guarantees to have access to distribution channels, these presuppose an endowment of digital technologies, therefore these are essential elements to be able to stay in an increasingly global supply chain. I am thinking of the international one, of export companies, etc., and therefore the more structured, more robust, larger, younger companies could be the ones that, at least in the initial phase, are the ones that benefit from it."

The third group of actors most mentioned in this section is the input industry, technical means, agrochemicals and machinery. These sectors are generally populated by large industrial groups that are already in dominating positions to offer products and services to farmers and thus to enter the new market opportunities. Furthermore, especially in the case of agrochemicals and fertilizers industry – the recent EU policies aiming at reducing inputs use are pushing these actors to diversify their business and, sometimes, radically changing their business models, from products to service selling. When the focus moves to those categories who might risk more, the experts reach some consensus in indicating small-medium farms and unskilled labour. As described in the previous and following sections, the main reasons behind this thoughts reside on both objective difficulties in adoption process and the technological offer less aligned with the needs of these subjects.

Following, at the same level of risk perceived by the experts, there are two different types of actors: input industry and actors from agriculture knowledge and innovation systems -AKIS. For what concerns the formers, some interviewed referred to the risky on-going process of transformation of the businesses that, as described above, it might be fatal for some large industrial groups failing to adapt to changes.

"In the input suppliers, the two sectors dominate, so on the one hand you have the machine of the other and the chemistry. I have spoken at high levels with various companies in both industries and they are reviewing their business model. Both therefore, they are aware that the digital revolution is not a passing phenomenon, but it is here to stay

and that if you embrace it and stay in the market, you can also earn a slice of the market, if you get it wrong you can even blow up."

Agronomists, technical assistants, extensionists and similar figures are also subjects that might suffer this process of radical transformations of the services they are used to offer. Indeed, on the one hand the coming diffused use of new devices at farm level might stimulate a significative request for assistance and support. On the other hand, demand for new services might assume new important efforts to adequate assistance offer and stay on the market.

c) Reflexivity

This section discusses on the different scenarios of societal impacts depicted in the previous section, trying to elaborate on the consequences of each of them. For what concerns the entry mode of different technology providers, various enabling/hindering factors might play a decisive role. These include the increased demand for digital services among agricultural operators, which can develop the necessary economies of scale that would justify the entry of some high-tech champions. This phenomenon is in turn influenced by both technological and economic factors; firstly, the data policy and in particular the data standard play a crucial role. Whether the agricultural data produced will be open and will use a common standard, various digital technologies at different steps of the data value chain might be able to communicate and transfer data and related information. This might solve the problem of incommunicability between technologies commonly denominated "interoperability". Moreover, this might open up the private digital environments that most technology providers are currently setting in their products/services sold. And this aspect relates to the economic factor: by setting common and open data standards, those actors more able to exploit economies of scale might win the current competition between many apps, platforms and similar environments offered on the market.

"On this much will depend for example on the possibility of keeping data systems open. If we start to introduce the possibility of open data then the platform providers will become the central element in my opinion. And there, it would be interesting to see precisely if in agriculture there are sufficient economies of scale to make platforms like Google that are for all farmers, because even there a monopoly will surely be created. In short, it is very likely. Eh, but it is necessary to understand if there is a market large enough to guarantee these big data, this economy of concentration. But here, I see, these platforms might have a central role…"

When the second group of younger, more professional agricultural operators active in contexts of large farms is considered, two main group of potential consequences might be identified. On the one hand, digital technologies whether adopted and implemented in routinely operations might raise the overall decision making efficiency and of the agrifood supply chain, - by favouring a smoother and more disintermediated exchange of information between the different actors:

"*Perhaps I see there more the advantage of those who will be able to use the data to make investments or to direct the production. And in this even the agricultural world could have a great advantage, that is, if today there was instantly the map of who is producing what between competing countries we would not have, for example – to stay in Emilia Romagna – farmers from Ferrara province that every year rack their brains to decide «what am I going to plant this year?»*

On the other hand, as highlighted on the risks section, one consequence might be that being the technological offer more designed for successful adopters, the marginal market of small-medium farms and unskilled operators might be unserved and cut off from the entire process. In facts, the experts interviewed described an on-going process of transformation of the agricultural society expressed also in the forward-looking exercise; "hobbyist" will gradually decrease as well as the smaller farms, that will be more and more aggregated in larger entities also as a result of a generational replacement. The digital technologies are expected to enhance this process: smaller and less professional farms face objective barriers to the adoption of digital technologies that might exclude them from this process of enhanced competitiveness, with resulting reduced commercial possibilities. Furthermore, the entire world of unskilled labour and technical assistance might be strongly affected; seasonal, unskilled field labour might be substituted by the automatization of some processes, as well as some more technical figures such as technical operators, drivers, etc.

"These are the actors who represent production structures characterized by a high age of the conductor. Basically, therefore, a lower propensity to change. I am not saying that ... it is not a lower propensity linked to the unwillingness to innovate, but it is linked precisely to barriers of an objective nature, in short. The smallest are those who have more difficulties, the older ones are those who have more difficulties, the financial barriers are higher in reality for very small dimensions and this is a fact on the innovation adoption, therefore I would find the difficulty and the critical issues especially at this level…"

In respect to the third group of subjects more favoured by digital technologies – actors from input industries – the experts report evidences of the interest shown by these groups on the sector of the digital agricultural services. In general, as reported in the quote below, the shift from products to digital services – phenomenon often described as *servitization* – is promising in terms of increasing market value, especially with the prospect of reduced agricultural inputs imposed by recent industry policies. Nonetheless, the same experts recognize how the business transformation input industry has to deal with poses serious issues, especially to the larger, traditional groups. For this same reason, these industrial actors are also mentioned among those stakeholders who might risk from the digitalization affecting agricultural services:

"Much will depend on how these processes are addressed, but if we see what has happened so far, it is the input suppliers who are all structuring themselves to move from hardware supply to supply of data services. That is in fact John Deere and now he sells you the tractor but he sells you – and more and more he will sell you – the service the platform on which you put the data, the way to manage data and it will take your data, so surely this is an area of competition very strong for suppliers. And it is not certain that producers will win; that is, there are those who say that, for example, in this game the manufacturers of machines are winning, because they collect in data compared to producers of seeds, fertilizers, etc., which in any case must depend on the data which supplies the machine."

For what finally concerns AKIS actors, the new array of competences requested by the modernization of agriculture might push out of the market those subjects who are not able or do not want to acquire new digital skills or to invest in new needed equipment. In facts, the same assistance is increasingly moving to digital modalities and already various professionals are already called to offer their service offer on online channels. In the future this process is expected to intensify and, as might happen for other field-related figures, those who might not be able or do not want to align to this phenomenon, might be finally substituted by on-line/virtual services.

"And then the whole system of knowledge, therefore all the technicians in the agricultural sector, these are destined for a radical change, that is, many things that were done by going to the company and today the computer does them, directly from the platform and therefore also the technical assistance will be reinvented. And, those who can't adapt will likely have a hard time if they don't adapt. Apart from that, now there are few agricultural technicians because they have dismantled all the knowledge services. But here are the ones that are still there: or they too convert to the new data economy or it will be difficult that they can be still competitive, and they are surely going to be losers."

d) Responsiveness

This last section invites all participants to the innovation system to question about what proposal can be advanced and what things can be done to "adjust courses of action" with the aim to set a responsible research and innovation process. To this aim, the author asked respondents to list and rate a) the most important measures to promote for a socially sustainable diffusion of SFT; b) to indicate who, in their opinion, might be able and it is in the position to pursue such measures.

Regarding the measures, there was considerable consensus in indicating training and education for the actors involved in the digitalization process as the first priority intervention. The promotion and the operationalization of training and education activities regarding the use and the control of digital technologies was indicated as the first needed strategy, with the aim to both avoid the risk of digital divide described above and to safeguard those actors who might risk the most. Some interviewed talked about specific training, assistance and consulting policies with reference the regional development plan (PSR in Italian, specifically measures 4 and 2, respectively financial resources for investments in intangible fixed assets and consulting, substitution and assistance in farm management). Some others proposed new, less traditional ways to train agricultural operators, as for example through itinerant trainers in different territories, especially in those more marginalized (inner or geographical dispersed zones), by directly involving digitalized agricultural entrepreneurs in training sessions or through applied demonstration of possible utilizations of digital technologies on the field.

"Then there is a problem that is connected to the last answer, (…) and let's call it training. And there are in my opinion three directions. One is divulgation and there is not such a thing. We need to divulge this information, talk about it better in different contexts. Yes, that is, on multi-level, multilayers, to reach the various interlocutors. Trying to be clear, trying to be detailed with practical examples, not talking about digital in general, but about some characteristics, obviously depends on the type of interlocutor. The second is training. So to create training courses. And even there, always in my opinion, things that are quite practical, operational, so things that you need, learning by doing, quite specific. Let's imagine, the farmer over fifty who is not very familiar, and I go to talk to him about Windows or how a digital system works, I show him the APP .. Third aspect, the demonstration. "

The second most cited proposal regards financial resources to dedicate to investments in digital innovation. Here most of the interviewed talked about the need to make available innovation funds to sustain the modernization of equipment – a key measure for an under-capitalized sector such the agricultural one. Various interviewed brought the national Italian law "Industry 4.0" as positive example. Some others experts underlined the need to direct such resources according to a national digital development agenda, to avoid that public funds would lead only to new equipment without more efficient and sustainable agriculture under the economic, environmental and social point of views.

"Some interesting cases I have seen in some countries was using innovation funds. In Uruguay, for example, but not only, just not to stay close to home, where in part what I said before is Emilia Romagna, Veneto, where practically access to funds has substantially incentivized the farmer who makes choices of use of innovative services and is remunerated. There is a way to do it a little cleverly, so avoid having to just put an antenna on a hoe to get you to take an incentive. That would be an intelligent thing to do, that is, to ensure that this lever of innovation is true, that it truly translates into a response, that is, into positive externalities. And social, economic, environmental. Otherwise, it becomes a little bit of a joke…"

The last proposed measure most cited by experts is at the same time one of the most articulated: a public-private partnership to shape and regulate the process of digitalizing agriculture. In the varied experts' opinions, agricultural data management represents the central issue to handle. On the one hand, public-private forces are called to intervene for the regulation of agricultural data for what concerns privacy and other rights of the data "originators", namely who produces these data on farms. So far, there is still some confusion on who actually owns data, who can benefit on data elaboration, how value is distributed. From a legislative point of view, some experts proposed codes of conduct as a way to regulate use of agricultural data by the different actors. Codes of conduct are soft law tools, statements of private nature where different actors commit to follow an agreed conduct on a specific issue. Some other experts propose a sort of "data cooperative" as a solution to store and manage data with shared ownership and decision making. On the other hand, public-private partnership are thought to be a suitable collaboration's modality to develop a common, open data standard, to avoid the risk of interoperability among different devices and a consequential hold-up risk from users' side. Indeed, with a mix of competences from private actors and public coordination it might be easier and more efficient to reach the definition of a free, common language regarding agricultural data.

"On the other hand, one could say, public tenders could be held - I remember the Consip race, at the time the State computerized the state procurement system – to be promoted within universities. The state might form a consortium and give real contributions - not what they have now - to a pool of universities that develops, for example in Italy an open and transparent platform for data sharing, which is interoperable with major machinery manufacturers and sets clear standards for all Internet policies of things. Whoever does this has a competitive advantage over all other nations."

When we asked experts who in their opinion should be responsible to promote these interventions, larger consensus was reached on Public, central bodies (as Government, Ministry), University and Research centres and Organizations with aggregating functions. The first two actors' category are pretty in line with the type of measures described above, as observable from the experts statements reported below.

"I think that the state must limit itself to defining clear rules, that is, it should define a committee of experts that defines the rules that turn into law. And that allows the process to manifest itself rather than restrain it. On the other hand, as I said, they should use public resources to incentivize this adoption process and they absolutely should involve research centres and universities actively in this process"

"Universities at research centres should develop at their own cost together with the Community, an open source open platform. Which then becomes a de facto standard. This would be the best possible solution for the industry, because

it would accelerate adoption benefits everyone and it would limit the situations of monopoly oligopoly on the part of some, thus attributing too many privileges to some elements of the chain, to the detriment of all. And it would solve the issue of interoperability and then of the formats and so on. And such a platform should also have one transparent policy, fair in data management because data will be the final commodity of digital agriculture "

The reference to "Organizations with aggregating functions" requires more details. Firstly, these are different type of organizations: experts referred to both farmers' associations as well as farmers cooperatives. In facts, these are different type of organizations according to their nature and purpose. Nonetheless they aggregate farmers and similar SFT potential users and are able to provide aggregated services, assistance and consulting differently from other private actors. Secondly, especially the cooperatives and similar institutions, they represent key intermediary actors from a commercial side; in doing so, they are periodically in contact with productive realities to offer productive assistance and consulting. Moreover, cooperatives and similar institutions are able to involve different professionals in their supporting activities (e.g. agronomists, several type of technicians, etc.) and might have necessary resources and network to trigger investments in digital tools and infrastructures in a more efficient way. Finally, between organizations and producers, there is often a relationship based on trust and mutual understanding, key factors when it comes to issues such as data sharing and management.

"In reality there are farmers associations, that is, these three gentlemen, very important in the our country, they should sit around a table and say: look, we represent agriculture because in three subjects we have in hand to pass me the term, a million Italian farmers and we need these things…"

"The large cooperatives, which are made up of members, who in turn receive the information, let's say by the technicians of the management of the cooperative, which they belong to. So now the path could be that within the same cooperative there are reference figures for technological innovation (…). In reality it would be necessary to have a figure, it would serve to think in perspective, and to say: I have inside of my company a figure who takes care of this. 1-2 figures who manage, let's say innovation technology, data, data management and the connections of the digitization process ".

Second round

The second round summarizes experts' view throughout all the sections, by giving an agreement's score to pre-defined statements. General agreements can be measured looking at mean and medians for each statement, while the consensus can be measured looking at the inter-quartile score (see table 10). Starting from the definition given to the process of digitalization in the Anticipation section, there are not great deviations from what found in round one, except for the most agreed definition which defines Smart Farming as an ecosystem able to foster agricultural actors connection, enabled by digital technologies for communication and management. This connotation was preferred by the majority of experts to the second and third most voted definitions, which in turn highlighted both the centrality of digital tools and their applications' contexts. For what concerns main benefits and risks, there are not great changes in respect to first round: on the benefits side, input and thus cost reduction seem to be the one more expected, followed by supply chain traceability and farm management efficiency. On the risks side, the potential gap that digitalization might bring in the agricultural society is envisaged as the principal risk and is perceived as digital divide, especially on the market/commercial sphere. The main change observed with the second round relates to the higher consensus put on the absence of a common and open data standard, with the consequential technological lock-in threat.

In closing this section, when experts have been called to indicate the main potential future scenarios, the second round partially confirms what came out in the step before; the main divergence consists in indicating a digitally interconnected, transparent, efficient and disintermediated food supply chain as the second most likely scenario as a consequence of the digitalization of the agrifood sector.

Table 9 - First round Deplhi findings. Codes and references.

Section	Query	Codes		
		1°	2°	3°
Anticipation	Definition of Smart Farming	Digital tools to collect and elaborate data for decision making (14)	Not a unique definition, diverse, more advanced in some contexts (5)	Emphasis on labels, advanced digitalization is not real yet, poor diffusion and data valorization (4)
	Greatest benefits from diffusion of SF	Farm management more efficient (31)	Supply chain management more efficient (13)	Costs reduction from precise use of agricultural input (13)
	Greatest risks from diffusion of SF	Digital divide (36)	Technological offer not aligned with demand (21)	Concentration of dominant players (13)
	Scenario of future agriculture	Professional agriculture, concentration of small and medium farms, less labour force (10)	More robotized and automatized agriculture (7)	Digitalization will support the sustainable intensification of agriculture (7)
Inclusion+Reflexivity	Actors who might benefit from SF	Technology providers (13)	Innovative farmers (12)	Input (technical means and machinery) industry (10)
	Actors who might risk from SF	Small-medium farm, unskilled labour force (11)	Input industry (4)	Actors from AKIS (4)
Responsiveness	Measures to promote a socially sustainable diffusion of SF	Training and consulting for digital innovation (19)	Financial resources for targeted investments (10)	Public-private partnership to regulate digitalization (9)
	Actors who should promote these measures	Public, central bodies (Government, Ministry) (13)	University and Research (9)	Organizations with aggregating functions (8)

Table 10 - Second round Delphi findings. Median, means and Inter-quartiles measures of most agreed statements

Sections	Round 1	Round 2		
ANTICIPATION				
Definition		Median	Mean	IQR
It is a digital ecosystem that facilitates relations between the various players in the agricultural system, enabled by specific digital technologies active in management and communication	-	4	4,22	1 (4-5)
It is the use of one or more digital technologies by a farmer and / or other agricultural operators	1°(-)	4	3,72	0 (4-4)
There is no single definition, there are different uses of digital in agriculture depending on the various contexts and areas of application	2°(-)	4	3,72	1(3-4)
Benefits				
It allows a more precise use of production inputs, therefore their reduction	3°(+)	4	4,33	1 (4-5)
It allows a better traceability of the product along the supply chain	2° (=)	4	4,28	1 (4-5)
It makes the agronomic management of farms more efficient	1°(-)	4	4,22	1 (4-5)
Risks				
The digitization process in agriculture can lead to a situation of gap between those who cannot access these technologies (for infrastructural, technological, financial reasons, etc.) and those who succeed	1° (=)	4	4,06	0,75 (4-4,75)
The lack of a common and open data standard (open source) can lead to technological lock-in phenomena in which the end user remains linked to a technology supplier without being able to transfer their data to another supplier	4° (+)	4	3,89	0,75 (3,25-4)
Farmers and other agricultural operators who do not use digital technologies will find it more difficult to enter and stay on the market	-	4	3,78	0,75 (3,25-4)
Future Scenarios				
Digital will accelerate the shift to a more modern agriculture run by younger, more professional farmers	1° (=)	4	4,11	0 (4-4)
Digital will lead to a more digitally interconnected, transparent, efficient and disintermediated food supply chain	4° (+)	4	4,11	0,75 (4-4,75)

Digital will support a transition process toward sustainable intensification of agricultural production	3° (+)	4	4	0 (4-4)
Agriculture will be increasingly robotized and automated with less manpower	2° (-)	4	3,89	0 (4-4)
INCLUSION + REFLEXIVITY				
Beneficiaries				
Structured, specialized farmers open to innovation	2° (+)	4	4,33	1 (4-5)
Start-ups and small and medium-sized companies providing digital technological solutions	1° (-)	4	4	0 (4-4)
Large providers of digital technology solutions (platforms, complete digital environments, etc.)	1° (-)	4	3,94	0 (4-4)
Actors at risk				
Unskilled labor	1° (=)	4	4,33	1 (4-5)
Small and medium-sized traditional, non-specialized farms	1° (=)	4	3,83	1,75 (3-4,75)
Companies supplying various agricultural inputs	2° (-)	3	2,72	1 (2-3)
RESPONSIVENESS				
Proposals for measures				
Training courses for actors in the agricultural sector	1° (=)	5	4,61	1 (4-5)
Consultancy courses for actors in the agricultural sector	1° (=)	4,5	4,44	1 (4-5)
Targeted financial resources to support investments in digital innovation	2/3° (=)	4	4,33	1 (4-5)
Infrastructure renewal interventions for widespread connectivity in the territories	4° (+)			
Design and proposal of simpler and more user-friendly digital technologies	10°(+)			
Promoters				
Organizations with aggregating functions	3° (+)	4	4,17	1 (4-5)
Public, central bodies (Government, Ministry)	1° (-)	4	4,11	1 (4-5)
Public-private partnership	-	4	4,06	0,75 (4-4,75)
University and Research	2° (-)			
Role of public actors				
Financing of the infrastructure renewal process (i.e broadband and network coverage in the national territory)	-	5	4,50	1 (4-5)

Funding of a training process in the use of digital technologies to the various agricultural actors involved	-	5	4,39	1 (4-5)
Targeted funding to support the adoption of digital technologies by agricultural operators	-	5	4,33	1 (4-5)
Funding and coordination of research and development for the creation of a common and open data standard (open source)	-	4		

When it comes to the potential effects on the actors who compose agricultural society, the second round confirm results from the previous experts' consultation, with small deviations. Among the actors who might benefit the most, experts' indicate innovative farmers first. Differently from the first round, technology providers are appointed as the "second" winners, with high-tech start-ups and small-medium sized firms who are expected to benefit (slightly) more than large providers. Regarding actors at risk, unskilled labour force and traditional small-medium farms are again indicated as the ones who might be more threatened, because potentially not able to reach higher levels of competition brought by digitalization of the sector. The third category of actors more nominated in this sub-section is "Actors from input industry"; nonetheless, looking at the consensus measures, the score 2,72 over 5 shows that experts actually disagree on the possibility that groups from input industries might be seriously damaged by the diffusion of digital technologies.

Finally, also for what concerns the responsiveness section, experts confirmed what highlighted in the first round: training and consulting courses together with targeted financial resources were the proposals which collected the higher consensus as found from the interviews. Differently from the qualitative step, several experts considered infrastructural interventions for digital connectivity as a priority intervention as well as an improved user-friendly design for an improved user experience. These proposals, although different in nature, got the same score and both should support the diffusion of Smart Farming technologies among agricultural users. When the experts were asked about who should promote these measures, they indicated the same main actors they mentioned at first round but in a different order: it is important to note that organizations with aggregating functions (farmers associations, cooperatives etc.) received the highest score (4,17), followed by different public actors: Public, central bodies (Government, Ministry), Public-private partnership and University and Research. Given the importance given to public sphere, another last question was added only to the second round. Experts were asked to indicate what should be the role of public actors in shaping the digitalization process. In general, these were indicated as the responsible for the main measures cited above, namely: financing of the infrastructure renewal process (i.e broadband and network coverage in the national territory), funding of a training process in the use of digital technologies to the various agricultural actors involved, and targeted funding to support the adoption of digital technologies by agricultural operators. It is important to highlight that among the interventions that reach the highest consensus, there is the funding and the coordination of research and development for the creation of a common and open data standard (open source). Here public actors are pointed out as crucial actors to orient innovation process towards openness, accessibility, transparence and data standard seem to be a key issue in this challenge.

4.5. Discussion

The group of experts, interviewed in two rounds, gave responses that did not change considerably in between the two consultations, showing a good level of consistency and a general agreement on the scenarios delineated.

Starting from the anticipated future scenarios, the experts reported about a structural change that is currently taking place in Italian agriculture: farms are decreasing, becoming larger and managed more professionally by younger and more educated farmers. On the one hand, this generational replacement is thought to boost the innovation process brought by digital technologies, generally more easily adopted and used by younger generations and more aligned with their professional needs. On the other hand, the process of digital innovation might support a transition towards a more innovative and performing agriculture, by both bringing more efficient technologies and new competences from other industries. In line this perspective, most experts agree in defining smart farming not only as the diffused use of one or more digital technologies by agricultural operators, but as a real new digital ecosystem where different figures are able to collaborate and more easily share information, knowledge and competences. Most of the experts seem to indicate that the digitalization of the sector might strongly support a paradigmatic change for what concerns both information/knowledge exchange and relationships enabling, from multiple sides: commercial, assistance, administrative, etc.

In addition to this view, when asked about Smart Farming definitions, experts seem to give two main different responses: one the one side, as shown in Table 9 several experts agree on saying that is difficult to attach a single definition to the phenomenon of digitalization of agriculture, which might have different applications depending on the contexts. To give an example, smaller and little specialized farms might still use simple FMIS to manually collect data about phytosanitary treatments and agricultural operations, as well as units to measure site-specific data (moisture, temperature, etc.), as a decision support system. Nonetheless, it might be hard to compare these applications with those observable in large, arable farms where VRT technologies in combination with autonomously operating machines might lead to a much higher farm's automation and complex digitalization level. Indeed, different labels have been given to the increasing diffusion of these technologies, such as "4th Agricultural revolution", "Agriculture 4.0 or 5.0", "Smart

Farming", "Precision Farming", etc., with a consequential confusion about what are the real differences among these appellations.

Regardless the definitions and contexts of application, the experts agree in identifying most benefits attainable from Smart Farming around an improved efficiency in farm management, in particular through an optimized use of inputs (water, agrochemicals and fertilizers). On the one hand this brings to their reduction, thus costs savings. On the other hand, a more precise use of inputs is expected to bring to overall better agronomic practices, as third most important benefit according to the mean value of agreement reported in table 10. For all these reasons, farmers and other agricultural operators open to these innovations, who could afford and use them, were considered as the most probable beneficiaries from Smart Farming diffusion (see Inclusion and Reflexivity section). In between these two envisaged benefits, digital technologies are also thought to improve traceability and transparence along the agrifood supply chain. In this sense, data that are more easily collected at farm level are also more easily transferred and elaborated along the supply chain with innovative modalities, such as the distributed-ledger technologies – DLT. On the one hand, that might speed up food tracing and other supply chain management's practices; On the other hand, more and more updated information on production, processing and following steps might be delivered to final consumers, bringing transparency for which buyers might be willing to pay higher prices.
Given all these expectations about the diffusion of these technologies, it is easy to understand why the experts consider digital technology providers among the main most probable beneficiaries. Various participants expect that both large groups not belonging to agriculture and highly innovative and specialized agritech start-ups will be able to reap the advantages coming from the digital. Large high-tech giants are expected to eventually enter agri-tech industry, when the diffusion of digital technologies will be widespread enough to reach economies of scale. At the same time, innovative, more agile start-ups and SMEs are already offering most of these services available in the Italian market. Although so far these smaller, highly innovative and specialized firms seem to be the ones better positioned in the market, some experts expect heavy competition between them until few dominators will remain, with some of these firms being acquired by large groups from the agricultural input industry[9].

[9] An example is the case of Monsanto Company acquiring Climate Corporation, a start-up focusing on digital agriculture services, for $1.1 billion.

When asked about risks and the relative threatened actors, the participants show a lower level of common agreement, with one exception regarding the primary risk identified (reflected on both the 1st and the 2nd rounds), namely a probable situation of digital divide as a result of a fast, uncontrolled diffusion of SFT. The threat of a systematic difference between actors able to accede digital technologies and those who cannot, is by far the most prominent, with an average value of 4 over 5 and a considerable general consensus (IQR equal to 0,75). Moreover, the third most "voted" risk is also considerably related to digital divide gap, and it is represented by one of its potential consequence on the commercial level: farmers and other agricultural operators who might not be able to use digital technologies might find more difficult to enter and stay on the market. These views on potential risks are in line with the findings regarding the actors who might risk more; by looking at the consultations from the second round, the first two positions are occupied by actors showing an average lower propensity towards innovation, namely small and medium-sized, traditional farms and unskilled labor. For these figures might be difficult to accede these technologies for financial, cultural and technological reasons. The concept, which has been very well described by some interviewed, is that technological innovations naturally impact the society by creating a situation in which a share of a certain population might be able to accede and exploit innovations' potential, while the remaining part might not. As discussed in several studies which followed a RRI approach, these types of impacts coming from innovations might reflect underlying values and/or dynamics of the same society (or part of it), as well as the program of an agenda – if existing – which defines goals and finalities of innovations introduced. In this sense, experts seem to depict a future scenario in which, following the *business as usual* direction, the advantages coming from SFT might not be collected by everyone, with the actors in the natural weaker position along the supply chain who might suffer more. This situation might be due to several reasons: the existence of a technological offer which is not thought and designed for some of these actors, the persistence of cultural and financial barriers to the adoption and/or the absence of an agenda/plan to design and manage the digital transition at the general level.

This last phenomenon is partially related to the second type of risks described by the participants, which is more technological in nature and relates to agricultural data standards. At this point in time, there is not at an European Union level a common, specific law/regulation on agricultural data management. The central issue of who owns agricultural data and who is in the better position to control and valorize them, although increasingly discussed at many levels (academic, policy, managerial, etc.), is currently regulated by only a code of conduct promoted by a consortium of important organizations representing European agricultural system (among the signers COPA-

COGECA, CEMA, CEJA, etc.)[10]. By definition, Codes of conduct belongs to the group of "soft laws" aiming at giving voluntary but not mandatory legal boundaries to social phenomenon. The absence of a clear regulation on the agricultural data practices leaves space to the market-based regulation which rarely takes timely into account all aspects of social importance (e.g. access, value distribution, etc.). Moreover, a state of legal indefiniteness might reflect the absence of a clear agenda to monitor and direct innovation impacts on the society. These aspects are not uncorrelated with the two different but connected source of risks mentioned in our study: digital technological lock-in due to the absence of a common, open data standard and the (consequential) concentration of dominant players, able to set their closed digital ecosystem. In this way, without clear rules nor incentives to manage an open and common data standard, experts envisage the risk to finally have closed digital ecosystem run by few technology providers' companies. In case these players might concentrate in their business different types of information (as in the case of agricultural inputs industries) so to manipulate the market, the risk of information monopoly might be a serious issue. To conclude, the third category of actors mentioned among the ones who might risk more are the companies supplying various agricultural inputs. In this case is worth to underline that the average rate given is actually low (2,72 over 5) meaning that experts are somehow indifferent to the possibility that these actors might risk considerably. More in details, some experts stressed the need for these players to change their business models, which must include digital services in their "value offer" to not being overwhelmed.

The final part of the study addresses the "Responsiveness" section of RRI approach, that aims at identifying what can be done and from whom, to foster a socially sustainable process of *agricultural digitalization*. Results do not vary considerably between the two rounds, especially for measures (and nominated promoters) who should address interventions of general/public interest such as the infrastructural, educational and dissemination ones. In this case, public bodies – preferably central institutions such as Ministries and Government – are indicated as those who should be responsible for the funding and management of: the infrastructure renewal process (i.e. broadband and network coverage in the national territory), training program for the use of digital technologies to and direct targeted financial measures to support the adoption of digital technologies by agricultural operators. Universities are also nominated as key institutions in this process, both for their function of centers of specialized education and for their role of scientific coordination of basic research projects. Regarding this aspect, some experts indicated the Universities as key figures to promote public-private partnerships, for example to jointly collaborate for the

[10] The full text of the proposal can be found at https://www.fao.org/family-farming/detail/en/c/1370911/

development of an open, common data standard. Last but not least, the experts underline the key role of organizations with aggregating functions in supporting the process of adoption and implementation of digital technologies (first by average rating value). These are cooperatives and similar producers organizations, farmers' associations and other organizations that establish relations on various levels with aggregated groups of agricultural operators (e.g. districts, consortia, etc.). Their role regards the operative support and advice in the adoption, implementation and assistance phases. Given the trust-based relations often existing between farmers and these organizations, their function becomes fundamental especially regarding data-related issues such as property, sharing and privacy. With respect to this, two issues are particularly important. The first one relates to the role that these organizations will play in the SFT *diffusion strategy*; several observers believe that it will be difficult to observe a direct and active adoption of these technologies by all farmers, for the several barriers described before. Therefore, the role that these "aggregators" might play as innovation brokers and managers might be key, especially in terms of valorization of data collected and value distribution to originators. Secondarily, which ones among the many category of organizations might be "delegated" to manage the digitalization process of the upstream productive phase, might be particularly interesting to research.

4.6. Implications and conclusions

Following a RRI approach, it was possible to take a picture of the on-going process of *digitalization* of the agricultural sector, by focusing on how this might affect agricultural society, what might be the needed measures to attain a socially sustainable outcome and on who should be responsible for such interventions. In line with the general overview of the study, the findings contain implications for many of the different actors that populate the sector and several research. Starting from the socio-economic implications, the experts envisage that SFT will be able to support the sustainable intensification of the sector, by improving production efficiency through optimization of inputs. Nonetheless, by following the current diffusion dynamics, SFT are not being adopted from every type of farm; on the one hand, some of these technologies fit better with extensive, intensive specialized and productive contexts. On the other hand, this poses an issue of digital divide, not only related to infrastructural reasons (e.g. broadband cover) but also to a mismatch between technological offer and the demand which is composed, especially in the Italian context, by small-medium enterprises and farmers, on average older and less educated then the national average. Regarding this point, the findings from the study propose priority activities to carry out, as well as those subjects who should be mainly responsible for such digital transition. Among these, organizations with aggregating functions are indicated as key figures, not only for their

potential role of innovation brokers, but also as potential key junction point for the digitalization of the entire supply chain.
Furthermore, the experts gave insights which might constitute interesting policy implications. Firstly, digital infrastructural renewal, training and consultancy and targeted financial support for the adoption of these technologies have been identified priority issues that central public body should fund. Moreover, Universities and mixed public-private partnerships are indicated as key figures for both basic technological research (e.g. for what concerns a common, open data standard) and dissemination of knowledge or digital extension services. Lastly for what concerns policy, the uncertainty regarding both the legal framework about data property and sharing, as well as the lock-in risks coming from the closed digital eco-systems are issues that require attention from policy makers, also in collaboration with other actors (public and/or private).
Finally, for what concerns research implications, this study offers several insights. Firstly, it represents a concrete example of RRI approach applied to the agricultural digitalization phenomenon in the Italian context and, at the same time, gives many additional insights on potential further applications. Furthermore, on a methodological level, the approach proposes a quantitative approach as complementary to qualitative data usually analyzed in these types of studies; this is thought to be helpful for explaining and confirming qualitative results. Secondly, findings stresses the disruption that is taking place in several competitive markets regarding agricultural industry, such as the machinery and agrochemicals industries or the technical advisory and knowledge services. As a consequence of this radical wave of innovation, several companies belonging to this sector have to review their business model. The investigation of how this technological transformation might impact the way some companies deliver and capture vale represents an interesting avenue for further research on this topic. Finally, but yet importantly, the same disruption dynamics are expected on the technological providers "arena", with an increasing competition among agri-tech startups or small and medium enterprises and new entrances by big tech players in digital agriculture industry. These industrial transformations represent interesting areas for further research.

Chapter 5

5. Overall discussion

The general aim of the different studies discussed in previous chapters is to describe the process of diffusion of digital technologies (here denominated Smart Farming Technologies – SFT) in the Italian agricultural context, from an extensive and comprehensive point of view. Different perspectives have been used to analyze the process of diffusion and evolution of this digitalization process, but the overall approach used in the entire work can be summarized in the study of: a) what the academic community previously investigated and reported about the adoption SFT, in particular through the structured literature review on farm-level MIS adoption reported in chapter 2; b) what the current main factors are that determine the adoption of SFT in the Italian context, with a focus on aspects mostly neglected by previous adoption studies (i.e. the role of organizational factors around adoption units as farms and farmers), through the empirical study reported in chapter 3; c) how the overall process of agricultural digitalization will evolve and might impact the Italian agrifood system from a responsible innovation point of view, through the Delphi study discussed in chapter 4. Proceeding in this way, it is possible to acquire and report a complete overview of the main dynamics that are currently shaping the digital transition of the agricultural system. On the one hand, these studies highlight the socio-economic effects that this radical innovation might bring to the traditional agricultural sector, both in terms of innovativeness/ competitiveness upgrade and disruptive impacts on some actors and categories of the whole sector. On the other hand, the evidence reported may indicate to policy actors on which aspects priority interventions and specific measures might be needed to guarantee a efficient, fair and inclusive agricultural digital transition.

The following sections discuss the main contributions from this study and highlight its main implications.

5.1. Main contributions from the study

Starting from the analysis of what has been previously investigated in terms of SFT adoption, it is useful to discuss the main findings obtained from the structured literature review regarding farm-level MIS. Within the group of agricultural digital technologies, apps or cloud-based FMIS represent the one mostly used by farmers at the Italian national level, probably for its acceptable benefits-cost ratio and its multifunctionalities in terms of productive, administrative and commercial support. Several international research projects (also funded by the European Union) focused on the development of MIS for agricultural systems, and many studies investigated their technological development and their adoption by farms. Nonetheless, differently from the widely explored group of PATs, there were not contributions in literature able to collect and systematize the evidences found by previous research on which factors explain the diffusion of farm-level MIS. The literature review analysis conducted allowed to fill this gap, by reviewing the main determinant factors affecting the adoption of these technologies, as well as the principal theories used to frame the analyses. Among the studies analyzed, many focus on the technological development of the digital solutions and report about technological barriers that might represent serious issues with the increasingly number of different devices used at farm level, as for example the case of interoperability (more details in the next paragraph). For what concerns more properly adoption determinants, the review underlines how previous adoption literature focused mainly on individual characteristics of potential "adopters" – in terms of both farms (physical and financial size) and farmers features (age, education). This is also linked to the main theoretical frameworks used (es. DOI) which favor the focus on potential "adopters" characteristics, while neglecting factors regarding the external context where the decisions are taken. In summary, these results identify a research gap in the potential role played by factors that are not directly linked to decision makers' individual characteristics, but that might reside in the context around farmers and affect their adoption behavior.

This overlooked aspect has been thoroughly investigated in chapter 3. The empirical study extends the research scope on SFT' adoption on two levels: first, it widens the analysis on a broader array of technologies, namely the 4 main groups of SFT identified by previous literature. Secondly, it widens the analysis of adoption, moving from one-off binary decision to a multi-step and multi-faceted process; in the first case, the study interprets adoption decision as a complex process where, before the actual yes/no adoption decision, conditions, influences and expectations contribute to formulate intentions to use and thus to adopt SFT. In these multi-processes, the study paid particular attention to the role of organizational conditions around decision-makers (*facilitating conditions*), on how these might affect expectations and intention to use relative to SFT. In the second case – *multi-faceted*, the analysis considers that the actual adoption decision might be affected by more factors put on different layers. Again, particular attention was devoted to the role of organizational environment around farmers, thus to the supply chain's organization they belong (governance structures).

The results obtained highlight several interesting points of discussion; starting from factors affecting expectations and intentions about/to use SFT, it is interesting to stress the important role of the social influence exerted on farmers when it comes to both the performance expectations about SFT and the following intention to use it. Trusted operators and/or collaborators, other colleagues and peer farmers were identified among the most influential actors. At the same time, the latent construct aiming at measuring the received organizational support did not perform acceptably in the model and this raises some points of discussion about key aspects; on the one hand, the expectations on organizational support might play a poor role in shaping intentions to use SFT, since organizations around decision makers still do not actively participate this digitalization process. This can be considered one of the major contributions of this study. On the other hand, the poor role of this construct might be explained by the poor expectations that decision makers might have on these organizational facilitating conditions. This last hypothesis can be rejected given the important role that key organizations have in the eyes of farmers and similar decision makers, when it comes to information sources and channels regarding SFT adoption (see next paragraph).

When the attention moves to actual adoption decision, additional insights in the role of external organizational context can be collected; firstly, the hierarchical integration of the supply chains that farmers declared to belong to (HI), shows a significant positive effect on the choice to adopt SFT. Supply chain's hierarchical integration measures the commercial integration of farms along the supply chain. HI positive effect on SFT adoption's probability gives it a considerable role in discriminating between potential adopters and non-adopters of these technologies. In this sense, these evidences underline the driving role that commercial network along the supply chain have in terms of innovation and competitiveness upgrade of upstream phases. Moreover, they confirm the great potential that digital technologies have for the entire agricultural supply chain; the upstream actors will have to deal with increasing digitalization of supply chain relations in the future, with implications on digital competences' prerequisites and, at the same time, good growth margins in terms of enhanced collaboration and efficiency – even for small and medium farms.

Besides organizational context, additional adoption determinants can be found in farms' size, both in physical (hectares) and economic terms (sales). These variables play a significant positive role on adoption decision, while seem to not affect the SFT decision "intensity". In this case indeed, only the intention to use SFT and sectorial specialization seem to be determinant factors. Overall, the adoption determinants identified depict the current scenario in the Italian context where bigger, specialized farms with a higher level of commercial integration along the supply chain seem to be the "early adopters" of SFT. On the one side, these evidences identify the current target for an increased diffusion of digital technologies at the farm level; on the other side, they pose the theme of if and how it will be possible to reach the majority farm-level base which present very different characteristics, especially in terms of size and productive specialization.

To answer to this and other related questions regarding the agricultural digitalization phenomenon, the last chapter of the thesis takes a forward-looking perspective and depicts probable, consequential scenarios on the evolution of the Italian agricultural sector in this digital transition. In doing so, the study contained in chapter 4 is framed through the concept of Responsible Research and Innovation, a theory widely used in several disciplines to investigate societal impacts that radical innovations might have, with the aim to generate a debate on the governance of innovation through a "collective stewardship".

The findings from the study allow to depict potential future scenarios, with main expected outcomes in terms of societal benefits and concerns, as well as potential effects on different actors of the agrifood system as a consequence of the digitalization process.

On the expected benefits side, the interviewed experts expressed optimism regarding a transition towards a more modern agriculture, populated by younger and professional farmers and accelerated by the diffusion of digital technologies. Digital technologies are thought to make possible a transition towards a sustainable intensification of the agri-food system, through a higher efficiency and transparence from farm to fork. In this picture, innovative farmers and technological providers (both innovative start-ups and large digital players) are indicated as the actors who might harness the benefits brought by digitalization, respectively in terms of higher production productivity and commercial potential. In the first case, these expectations are confirmed by empirical results found in chapter 3; for what concerns technological providers, the Italian context is indeed currently populated by many start-ups offering highly-innovative and specialized digital services, arrived on the market in recent years. On the contrary, large technological providers are still not entering the market: according to some experts, this is due to still low scales to justify an entrance of these groups.

On the side of the potential concerns, our findings pose the central theme of access to the technological progress brought by SFT from a multidimensional point of view (physical, financial, competences-related, etc.), with the consequential concern of creating societal inequality in terms of value retention and distribution. In this scenario, the actors who might be excluded during the digital transition might be the small-medium farms, identified by the experts as those actors who might risk more as a result of a higher competitivity to enter and stay in the market. These are followed by the unskilled labor force, who might be substituted by the automatization of some productive processes. For these reasons, in order to shape digital innovation in a responsible way, the AIRR approach used in the study highlights aspects of inclusivity and responsiveness that need to be considered. When asked about "what can be done" to make digital agriculture socially sustainable, experts indicate the need for direct support in the transition to new needed competences and services, by indicating training, consulting, targeted financial resources and renewed infrastructures (mainly referring to broadband coverage) as the leading ways to achieve this upgrade at the farm level. Moreover, the experts indicate different subjects who should be responsible for these interventions; the first actors' category identified is that of organizations with aggregating functions (es. producers organizations or farmers' associations). On another level, the basic, general institutional support proposals are advanced especially to public governing bodies (Ministries and Government mainly), while the request for better technological conditions and a clearer legislative framework in terms of data management is mandated to University and Research centers together with public-private partnerships.

5.2. Main implications from the study

In order to discuss the main findings obtained from the study, this section will discuss the major derived implications, considering both socio-economic and policy aspects. Throughout all the chapters several insights on the socio-economic development aspects can be collected, starting from the great economic emphasis put on the digital transition in agriculture, witnessed by the increasing diffusion of digital technologies at all the steps of the agri-food supply chain and the resulting increasing market value of this sector. Global digital agriculture market is estimated around US$ 13 billion in 2021, to reach approximately $21 billion by 2026 (CAGR 10%)[11]. Last updates in Italy revealed also an increasing trend, with a market value equal to about € 540 millions, +20% in respect to 2019 and +440% in 2021/2017 period (Osservatorio Smart Agrifood, 2021). These recent statistics for the Italian market confirm that a digitalization process started in the Italian agriculture too, with considerable dynamism on the demand and the supply side. On the demand side, the latest statistics reveal that approximately 4% of the UAA is covered by digital tools use, with farm-level MIS being the technology mostly diffused among Italian farms (see fig.

[11] Estimations provided by Smart Agriculture Market report by Markets and Markets, available at https://www.marketsandmarkets.com/PressReleases/smart-agriculture.asp

10 in Appendix 3.1). These statistics are in line with the findings obtained by the elaborations of data collected for the study in chapter 3 (see fig. 11 in Appendix 3.2).

In this perspective, results reported in chapter 1 offer interesting insights regarding factors that need to be considered in the adoption of these technologies (and therefore in their commercial success). Starting from the most cited aspects in the literature reviewed, the user-friendliness and easiness-to-use seem to be key technological factors for the diffusion of these devices. It is related to the last aspect, although treated separately in the previous section, the current scarce interoperability among different MIS or other digital technologies. This issue might represent in the future a primary barrier to the commercial diffusion of digital devices in agriculture, since they make considerably hard a combined use of different but complementary technologies at the farm-level.

Besides technological factors, the results obtained in both chapter 2 and chapter 3 suggest that socio-demographic factors may play a role in the uptake of farm-level MIS and the overall group of SFT; some ambiguity remains about the role of users' age and education. Although the literature review on farm-level MIS reports age and education as key factors, it is still not clear in the academic community whether these aspects play a real significative role in the adoption of the whole group of SFT. Indeed, although on average older and less educated farmers might suffer more the complexity of digital technologies, last evidences do not offer unique results on these effects (Shang et al., 2021), and the empirical study contained in chapter 3 adds to these contributions. On the contrary, it is generally accepted the key role played by farm size, in both physical and financial terms and all the studies contained in this dissertation support this thesis. Moreover, the additional contribution brought from the empirical study highlights the key role played by commercial integration along the supply chain. This aspect might be due to multiple reasons; firstly, existing commercial relations along the supply chain reduce uncertainty about commercialization of farms production and this might favor investments in innovation. Moreover, a commercial network around decision makers might give them the support and the incentives to renew some productive processes. Indeed, commercially integrated supply chain generally require a higher level of transparency (as for example for traceability purposes) and efficiency (e.g. reducing production costs and/or orders management) from the farm-level, therefore digital technologies might be needed to collect and elaborate data to keep commercial relations and stay in the market.

In this sense however, it is still not clear whether and how some actors might lead this process of digitalization of the whole supply chain, starting from the productive phase. In facts, the results obtained in chapter 3 show that adoption initiative of SFT currently remains more on individual base and leaded by *early adopters*, who on average conduct bigger, more structured farms that commercially integrated (hierarchically) along the supply chain. This group of farmers represents the target for the digital technology/service providers that might be generally addressed more or less directly, depending on the intermediation role that might be played by other actors upstream in the supply chain. In this light, agrifood processors showed in some cases the capacity to lead this renewal change, by having investment capacity and control over the downstream phases of the supply chain[12] (Blasi et al., 2015). Nonetheless, these examples are still sporadic at the moment, probably given the uncertainty that still exist around the technologies and its acceptance from suppliers, as well as the high cost of such investment.

When looking at direct engagement of potential adopters, the elaborations of data collected for the empirical study in chapter 3, show the most important actors and channels when it comes to information regarding SFT. On-farms demonstrations remain the most preferred modality to get acquainted with the functionalities of these devices, followed by seminars or courses and virtual modalities (web-sites) (fig. 12 in Appendix 3.3). When it comes to actors and/or organizations who might support and assist potential digital users, and thus play the role of digital innovation broker, the issue becomes more complicated. On the one hand, as shown in chapter 3, fig. 8, the large majority of the responding sample (80%) did not feel supported by any organization during the adoption process, whether they adopted already any SFT (72%) or not (91%) – Table 11 in Appendix 3.4. On the other hand, by looking at fig. 13 (Appendix 3.5), the first three categories of actors appointed by the sample as the main sources of information regarding SFT represent almost 50% of the preferences and are: producers organizations, personnel from agricultural machinery/farm equipment industry and farmers' associations' operators. Moreover, when the few respondents supported during the adoption process are asked to indicate from which figures they received support, again, producers organizations, farmers' associations and input and/or raw material suppliers were indicated. In summary, two distinct groups of actors might be identified as those playing an important role in shaping this primary phase of digitalization; the first one is represented by a commercially-driven group of actors who deals with the sales of SFT and associated supporting services and will be described in the next paragraph. The second group is mainly represented by organizations with aggregating functions (producers' organizations and farmers associations) and, even in the study presented in chapter 4, their role is deemed to be of crucial importance not only in the adoption of SFT, but also in their implementation (especially in the data valorization phases). This is especially true in the case of small and medium farms (*early*

[12] See the case of Barilla S.p.a that distributed DSS devices from the start-up Horta s.r.l to its suppliers of durum wheat within the project "Carta del Mulino". See Blasi et al., 2015

and late majority in Rogers' DOI terms) who might not have resources and competences to enter this transition individually. These organizations, especially farmers' associations, already represent for farmers the reference points for what concerns generic administrative and, sometimes, technical/commercial assistance. At this moment, several partnerships are being developed by some of the main farmers associations to keep their crucial role, especially in terms of training and consulting, that in the close future might evolve quickly in data keeper and "valorizers"[13]. In these terms, these organizations play and will play a fundamental role concerning agricultural data management with implications regarding data property and privacy. Producers organizations are even closer to these issues and in many cases they directly manage smart farming devices on behalf of the production members. Nonetheless, the findings from this thesis seem to reveal that organizations such as cooperatives, associations of producers' organizations (Aop) and similar appear to be lagging behind on this front.

On the SFT supply side, there is great excitement due to both the important market value that digital agricultural industry represent and the "hype" moment that is topic is living, also from a policy point of view. Although the considerations about the SFT's supply market represent a wide theme that might need a dedicated study, the following comments emerge mainly from the last study about socio-ethical implications of SFT reported in chapter 4. Here, especially in the inclusion section, the experts were called to comment on how digitalization might impact main agricultural actors. The obtained findings depicted a very turbulent competitive scenario; on the one hand, the increasing "digital agriculture" market value represent a *blue ocean* where many highly-innovative start-ups offering digital products and/or services are trying to enter. On the other hand, an important moment of "disruptiveness" is involving important agricultural industries, namely agricultural inputs and machinery/farm equipment ones. The reflexivity section then helps to outline what might be the consequences of these impacts and relative choices of some of the stakeholders involved. In the case of agricultural inputs industry for example, this is largely involved in a juncture where its main core business – mainly represented by agrochemicals and fertilizers production - is radically changing, also as a result of European policies that aims at reducing the use of these inputs. The considerable agricultural know-how of these industries - combined with their significant investments capacity - justifies the great interest expressed by the majority of the large groups from agricultural inputs industry in the promising digital agricultural industry[14]. The machinery industry, on the other hand, might have a competitive advantage in the

[13] See the examples of the partnerships between Confagricoltura and Coldiretti with Tim, and various other research projects (such as the Horizon 2020 Demeter or SmartAgriHubs)

[14] The main example is represented by the acquisition of Climate field view by Monsanto, then become Bayer.

area of technologies embedded in farm machinery (VRT and similar), thus in the products which manage and valorize produced agricultural data. In the middle, global digital technology providers frankly expressed their interest in this market; many experts from the chapter 4 reported about the possibility for high-tech giants to enter agriculture as soon as economies of scale would economically justify this move. Currently many partnerships between all these actors are being carried out[15], as well as several mergers and acquisitions between and/by start-ups and large groups active in these industries are expected in the next period. In the meantime, there is a large variety of business models for digital agricultural products and services, often based on agricultural data directly collected by farmers or similar operators and processed by these entities. It would be of considerable interest to study which of these business models might be the most successful for the whole ecosystem of stakeholders involved.

Policy implications

Since the first PAT definition and development around the nineties, there has been an increasing interest by policy makers on the potential application of digital technologies in agriculture. In 2019, 26 European countries signed the Declaration of cooperation on a smart and sustainable digital future for European agriculture and rural areas *"to take a number of actions to support a successful digitalization of agriculture and rural areas in Europe"* (EU member states, 2019). Since then, the focus on this topic did not cease to increase; EU green deal with the agrifood-related strategy "Farm to Fork" clearly refers to the need for a *digital transition* of the European farms (European Commission, 2020) (pp 16) and the new Common Agricultural Policy (CAP) reserves financial resources to support investments in digital technologies at the farm-level [16]. Last but not least, at the Italian national level, the recent Recovery and Resilience National Plan (PNRR) reserves almost € 500 millions to the innovation and mechanization of agricultural sector, financial resources de facto mostly devoted to incentivizing the digitalization of agricultural supply chain. These resources witness a general, diffused will to support this digital transition, as a way to achieve a smart and sustainable agriculture.

Some of the evidences from this thesis might be of interest of policy makers to help them in the definition and implementation of a common strategy to achieve an effective and fair *digital transition.* On the one hand, findings from this study might be particularly useful in the identification and the description of some risks that might derive from a fast digitalization process without a commonly-designed strategy. On the other hand, possible strategies to control these

[15] One of the last main partnerships is being announced between the agrochemical group Bayer and Microsoft, source: www.bloomberg.com/news/articles/2021-11-17/bayer-partners-with-microsoft-to-build-digital-tools-for-farming
[16] Both in the programmes 2021-22 and 2023-27, through second pillar, Next-generation EU and eco-schemes.

risks are advanced, as well as key actors that might be involved in the definition of ad-hoc policies about development and regulation of a digitalization process of Italian agriculture.
In this sense, one of the main evidences - well-documented through all the three different studies presented in previous chapters - regards the digital divide phenomenon. In this potential situation a substantial proportion of the population, identified by one or more shared characteristics, lags significantly behind others in the adoption of digital technologies (Warren, 2002). This might be due to sevearal reasons: technological, socio-demographic, infrastructural and structural (related to agrifood production system). Findings of this thesis highlights that in the SFT case, small and medium sized farms as well as unskilled agricultural labor and traditional operators might represent the proportion of the population at risk. On the one hand these figures have in common poor availability of resources, competences and infrastructures to embrace this digital renewal process. On the other hand, especially small and medium farms, represent a marginal market for suppliers of digital solutions, that in turn are more specialized in solutions for large and intensive productions. As a consequence, it is hard for smallscale farmers to find technologies that are compatible with their dimensions and needs.
The Delphi analysis in chapter 3 highlights the roles that policy might play to deal with this emerging phenomenon; firstly, financial resources to support investments in digital equipment must be targeted. In facts, it seems that the next period will be caracterized by considerable public funds available in this direction (see, PNRR, CAP and national public funds already available, as Industria 4.0 and "Legge Sabatini") thus clear rules and controls will be needed to avoid inefficiencies and externalities (spillover effects that favor other digital supply industries, for example). Secondly, training and consulting measures play a fundamental role. In both cases many subjects are involved but evidences from chapter 3 and 4 highlights the key role that aggregating subjects such as farmers associations and producers organizations might play as innovaton brokers. In that rispect moreover, the overall findings depict a scenario where potential users seek support and advice in the entire process of adoption and implementation of SFT, from informations seeking to usage and maintenance. So far, our evidences depict a scene mainly populated by private subjects with commercial-purposes. At the same time, many experts and farmers interviewed expressed a positive feedback regarding partially public-funded entities for agricultural and knowledge systems for innovation (AKIS) that in some Italian regions are still present (e.g. Sicilia, Campania etc.). These public-private subjects might play an important role for what concerns digital innovations. Indeed, continued programs of training and consulting, offered free from commercial purpose, might considerably support a facilitated approach towards these technologies, especially from the disadvantaged actors described above.

Last but not least, policy measures are needed to guarantee that such disruptive innovations do not jeopardize key aspects of the socio-economic system where agricultural actors operate, namely conditions for fair competition and privacy/security. The fair competition issue deals with several other different aspects, both technological and market-related; for what concerns technological aspects, the possibility to have a wide diffusion of homogeneous technologies with closed, controlled systems (Ehlers et al., 2021) might lead to many situation of incommunicability between different digital tools and, in the worst case, to phenomenon of technological lock-in. In the first case, widely described above as interoperability, the drawbacks consist in the reduced functionalities of these technologies, in the necessity to have multiple tools for different activities (e.g. greenhouse management, VRT dashboard, FMIS, etc.), with the consequential risk to overload users and having the adoption rejected. The second case is a direct consequence of the interoperability and regards the impossibility of potential digital users to migrate their agricultural data stored in a system to another one, thus remaining "locked-in". Also in this case, the consequence might be to slow down the adoption of these innovations, given the impossibility to freely dispose the owned agricultural data. Moreover, this risk might be strengthened by the concentration of dominant players on the digital technologies' supply side, which might impose a proprietary, closed data standard.

In this context, policy might act on two distinct levels; on the one hand, it should support research (public and through Universities) and private-public partnerships to develop a common and open data standard, in order to set an open and collaborative digital environment. This would foster both diffusion of digital technologies in agrifood system and further technological development, given the higher possibilities for different players to work on open data. On the other hand, policy makers should constantly monitor the development of the topic "digital agriculture" at the legislative and regulatory level. In this moment, the European Union position on this topic seems not to want to curb possible technological development with overly strict laws on ownership and sharing of agricultural data. For this reasons, soft law mechanisms (Codes of conducts mainly) are currently used to regulate data use and sharing in agriculture. With an increasing diffusion and use of digital technologies in agricultural contexts, it might be necessary to review the current methods with others clearer and stringent. These aspects are of fundamental importance when entering into privacy issues linked to data; with an increasing amount of agricultural data collected and stored, it is fundamental to have clear rules, laws and secure infrastructures for data storage, control and monitoring.

5.3. Limitations of the study and future research directions

The main limitations of the studies reside in the difficulty to grasp the vastness and the complexity of the phenomenon under analysis. In this section, the main limitations are reported for each of the studies contained in the different chapters. For what concerns the first review phase, with the aim to consider all the main contributions on the topic, a structured literature review has been carried out. This review methodology cannot be considered systematic since it does not follow all the recognized guidelines related to the systematic search and replication. In facts, we preferred to proceed with a review process with clear replicable phases that allowed us to consider the main studies focusing on farm-level MIS, without following the more structured systematic process that would have imply more time needed on this phase. That would have been inevitably detracted time from the following research steps of the thesis. Another limitation might be represented by the high-paced rhythm of technological development of SFT. Although we clearly defined the technologies to be considered within the review, technological development in digital agriculture is so quick that management information systems might considerably change their characteristics and as a consequence some of their adoption determinants.

The empirical analysis in chapter 3 also contains some limitations. In this study, although we extend the focus to more possible factors affecting adoption, we do not include variables such as agro-ecological or informational factors. Moreover, for what concerns the UTAUT model used, the FC construct do not perform as expected, as in other recent studies (see Michels et al., 2020). Before the application of the model in the study, a deepen review of previous contributions on similar contexts was carried out (see chapter 3, section 3.2.1 and 3.3 and table 2.2, Appendix) finding several existing applications of the facilitating conditions construct. We recommend future research to pay particular attention to the adaptation of this construct to the agri-food context. From an empirical point of view, a limitation of our analysis consists in the sample's nature; we refer to an existing on-line community of farmers, thus their attitudes towards technologies might differ from those of off-line farmers, probably less technologically advanced. Moreover, the study has a geographical limitation: it includes only farmers active in Italy. Our suggestion for future research on SFT adoption is to replicate multistep and multifaceted analyses, with samples more heterogeneous in terms of propension towards technology and geographical distribution.

Finally we report some limitations of the study contained in chapter 4. Delphi analyses are by definition partial in the representation of experts' view on the topic under investigation. Experts' pools, although selected and engaged according to a defined methodology, are limited and represents a view that cannot be completely exhaustive. Moreover, in our case, we followed a two-step round procedure to select and refine main ideas and concepts derived from the interviews and surveys. Although the selection and refinement procedures with more steps can lead to richer and more complete qualitative findings, we decided to keep short the data collection phase. This was done for two main reasons; firstly, a short but efficient data collection contributes to keep the drop out rate low, as it was in our case. Secondly, for such fast-changing phenomena, it is of utmost importance to set and implement a data collection which is at the same time methodologically sound but also non-dispersive, to capture main salient findings. Additional studies that use RRI approaches to digital agriculture's topics will be needed, to deepen and stimulate the debate on the evolving direction that agricultural digital transformation might take. Lust but not least, a limitation of this last study resides in the RRI approach which is explorative in nature and uses a forward-looking perspective; the various themes deriving from the Delphi analysis are not thoroughly investigated, rather being described and contextualized. This has to do with the main purpose of RRI analyses, which is to open up and stimulate the debate on potential socio-ethical issues related to science and innovation activities. Indeed, the in-depth analyses of some of the themes emerged from these studies might represent interesting avenue for further research; in details, the investigation of the digital business model transformation of some traditional agricultural stakeholders (i.e. agricultural input and machinery industries) as well as the evolution of the competitive scenario among the different types of digital agriculture technology providers, represent some examples of topics which might deserve more attention.

Chapter 6

6. Conclusions

This thesis aims at comprehensively analyzing the adoption and diffusion process of smart farming technologies which is occurring in Italian agriculture. Digital technologies are expected to strongly affect agrifood sector in the coming decades, to contribute to make agriculture more sustainable and smarter.

These expectations drive a great dynamism on the technological supply side, witnessed by significant growth rates in agritech industry observed worldwide. That said, when the focus moves to the actual diffusion of these technologies in agriculture, there is still uncertainty and several unclear aspects related to the adoption and use by agricultural operators, mainly farmers and similar decision makers. This is particularly true in the case of the recent and wider group of SFT, which are actually driving the process of digitalization at the farm level.

To this aim, this work starts with reviewing previous studies which focused on adoption of the most used SF technology in the Italian context, farm-level MIS. This first research step allowed us to review main adoption determinants and theoretical frameworks present in previous studies, as well as to clearly identify main research gaps relative to SFT adoption. Thus, the second study addresses some of these main unclear aspects related to SFT adoption process, namely the multi-step and multi-faceted aspects; in the first case, we set an extended theoretical model which allowed to analyze the farmers' (and similar decision makers) attitudes and intentions to use/adopt SFT. In the second case, we enlarge the view to additional potential adoption's determinants scarcely considered in previous research, with a main focus on the role of organizational institutions around potential adopters. The empirical analysis - carried out through a consistent survey-based sample - allowed us to test various research hypotheses and outline the main dynamics of the whole adoption process. In detail, our results suggest that, at present, the adoption decision remains primarily individual in nature, with the current adopters bigger, more structured farms more hierarchically integrated along the supply chain.

The third, conclusive step of this thesis starts from the results obtained in previous study to enlarge the view on the main dynamics that are shaping the digitalization of the whole agricultural sector. On the one hand indeed, the empirical study emphasizes how the digitalization taking place at the farm-level might be supported and/or influenced by organizations, institutions and other actors put at different levels of the agrifood ecosystem. On the other hand, digital technologies applied to agrifood affect in different ways and directions the entire society, within and outside the mere agrifood ecosystem. Given these premises, through an exploratory Delphi study, the study investigates the main socio-ethical implications deriving from the digitalization of the whole agricultural sector. The obtained findings shed lights on the enormous potential of digital technologies in terms of enhanced efficiency, competitiveness and overall sustainability. On the one hand digital transition is expected to accelerate the shift to a more modern agriculture run by younger, more professional farmers. On the other hand, such transition occurs with some risks, such as the ones to exacerbate a gap between digital haves and have-nots and/or to set technology lock-in phenomena. Overall, significant policy interventions are needed to guarantee a fair digitalization of the sector, while very different actors might seize the numerous opportunities that the occurring disruptive effects have created.

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8.Appendix

A.1 Farm level MIS adoption determinants found in literature

A.1.1 – Adoption drivers

	Ease of use, usability (D1)	Size (D2)	Education level (D3)	Possibility to customise (D4)	Relative Advantage (D5)	Training (D6)	Users' skills (D7)	Initial tech. equipment (D8)
Haberli et al., 2019					X			X
Carli & Canavari, 2014.	X							
Zheleva et al., 2017								
Carrer et al., 2017		X	X					
Kaloxylos et al., 2012								
Haberli et al., 2017		X			X			
Ibrahim et al., 2018		X						
Sørensen et al., 2011						X		
Verdouw et al., 2015				X	X			
Rosskopf & Wagner, 2003	X			X	X	X		
Sørensen et al., 2010						X		
Nikkilä et al., 2010	X				X			
Mackrell et al., 2009				X				
Lawson et al., 2011		X	X					
Fountas et al., 2015	X					X		
Sørensen et al., 2010								
Nurkka et al., 2007							X	
Barmpounakis et al., 2015								
Lewis, 1998			X					X
Kruize et al., 2016				X				
Tiffin & Balcombe, 2011		X	X					
Alvarez & Nuthall, 2006		X	X					X
Husemann & Novkovic, 2015	X			X				
Kuhlmann & Brodersen, 2001	X			X			X	
Engler & Toledo, 2010			X					
Fountas et al., 2009	X							
Batte, 2005		X	X					
Kaloxylos et al., 2014	X		X				X	

Fountas et al., 2015	X	X		X				X
Fox et al., 2018	X							
Pivoto et al., 2019		X			X			
Sopegno et al., 2016	X							
Steffe, 2000								
Allen & Wolfert, 2011		X					X	
Tsiropoulos et al., 2017	X	X	X	X	X	X		
Total	12	11	9	8	7	5	4	4

D1 **Ease of use, usability**
D2 **Size**
D3 **Education level**
D4 **Possibility to customise**
D5 **Relative advantage**
D6 **Training**
D7 **User skills**
D8 **Initial tech. equipment**

A.1.2 – Adoption barriers

	Interoperability (O1)	Age (O2)	Costs (O3)	Complexity (O4)	Data ownership and privacy security (O5)	Data standards (O6)	Time consumption (O7)
Haberli et al., 2019							
Carli & Canavari, 2014.							
Zheleva et al., 2017			X		X		
Carrer et al., 2017							
Kaloxylos et al., 2012							
Haberli et al., 2017				X			
Ibrahim et al., 2018							
Sørensen et al., 2011							
Verdouw et al., 2015			X	X			
Rosskopf & Wagner, 2003	X						
Sorensen et al., 2010							
Nikkilä et al., 2010	X			X		X	
Mackrell et al., 2009	X						X
Lawson et al., 2011							
Fountas et al., 2015	X					X	
Sørensen et al., 2010	X						
Nurkka et al., 2007							
Barmpounakis et al., 2015							
Lewis, 1998		X					
Kruize et al., 2016	X					X	

Tiffin & Balcombe, 2011		X					
Alvarez & Nuthall, 2006		X	X				X
Husemann & Novkovic, 2015							
Kuhlmann & Brodersen, 2001							
Engler & Toledo, 2010		X					
Fountas et al., 2009	X				X		
Batte, 2005		X					
Kaloxylos et al., 2014			X		X		
Fountas et al., 2015	X	X					
Fox et al., 2018							
Pivoto et al., 2019							X
Sopegno et al., 2016	X						
Steffe, 2000			X				X
Allen & Wolfert, 2011	X	X	X		X	X	
Tsiropoulos et al., 2017		X		X			
Total	10	8	6	4	4	4	4

O1 **Interoperability**
O2 **Age**
O3 **Costs**
O4 **Complexity**
O5 **Data ownership, privacy and security**
O6 **Data standards**
O7 **Time consumption**

A.2 Smart Farming adoption: an extended empirical analysis

A.2.1 – Governance structure classification and indicator of relative hierarchical integration

SC Governance structures classification (Wever et al., 2010) and measurement of SC hierarchical integration	
Spot market contract. A contract (invoice) for instant exchange of goods or services	Q1. I*s the production and/or the commercialization ruled by legal enforceable contracts?*
Verbal agreement. Exchanges not formalized into written, legally enforceable contracts. Performance or behavioral standards are unlikely to be specified, but if so, they are not formalized	Q2. *Do you receive resources and/or support for some of your business activities (e.g. production commercialization, etc.) from commercial partners to which you belong (e.g. producers organizations, suppliers, buyers, etc.)?*
Formal contract. Legal enforceable, written contracts are used to govern the transaction. Performance and behavioral standards are specified in the contract	Q3. Is y*our farm part of a cooperative, consortium or similar producers' organizations?*
Equity-based contract. A chain actor owns stock (and has the accompanying shareholder voting rights), but less than 50%, of (on of) its suppliers/buyers	Q4. *In the management of your farm, are you subject to control/monitoring from other actors of the supply chain you belong to?*
Vertical integration. A chain actor owns more than 50% of the stock (and has the accompanying shareholder voting rights) of (one of) its suppliers/buyers	Q5. *Do other actors from the supply chain you belong to own part your farm's property?*

A.2.2 - UTAUT constructs and measurement items

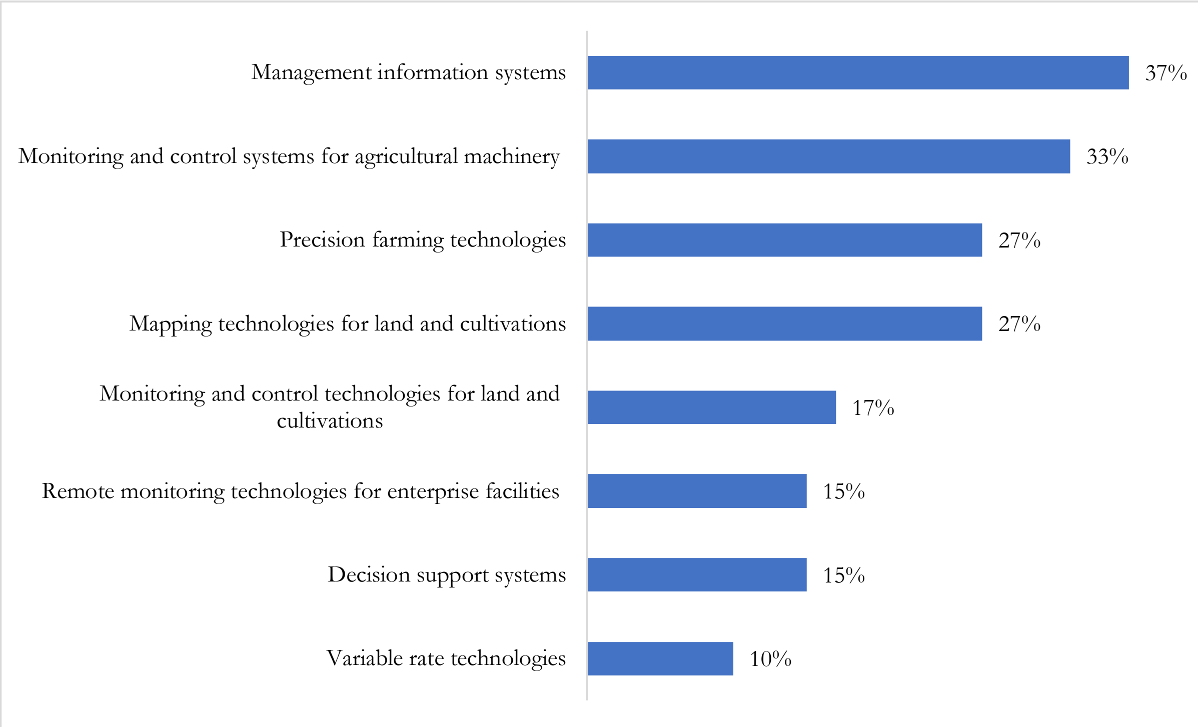
UTAUT constructs	**Items**	**No.**	**Source**
Performance Expectancy – PE	*I would find the use of SF technologies useful in my daily work*	PE1	Beza et al., 2018; (Beza et al., 2018; Venkatesh et al., 2003, 2012)Venkatesh et al., 2012, 2003
	I think the use of SF technologies makes my farm more productive	PE2	Beza et al., 2018; Caffaro et al., 2020; Faridi et al., 2020
	I think that the use of SF technologies makes the cost management of my farm more efficient	PE3	Michels et al., 2020
	I think that the use of SF technologies makes the management of my farm more environmentally sustainable	PE4	Michels et al., 2020

Effort Expectancy – EE	*My interaction with SF technologies is clear and understandable*	EE1	Beza et al., 2018; Michels et al., 2020 Ronaghi and Forouharfar, 2020; Venkatesh et al., 2012, 2003
	I think learning to use SF technologies is easy for me	EE2	Faridi et al., 2020; Beza et al., 2018; Michels et al., 2020 Ronaghi and Forouharfar, 2020; Venkatesh et al., 2012, 2003
	I think that SF technologies are easy tools for me to use	EE3	Beza et al., 2018; Faridi et al., 2020; Michels et al., 2020 Ronaghi and Forouharfar, 2020; Venkatesh et al., 2012, 2003
	I think it is easy for me to become proficient in using SF technologies	EE4	Beza et al., 2018; Faridi et al., 2020; Michels et al., 2020; Ronaghi and Forouharfar, 2020; Venkatesh et al., 2003
Social Influence – SI	*People I work with on the farm (agronomists, consultants, salesmen etc.) think I should use SF technologies*	SI1	Faridi et al., 2020; Michels et al., 2020; Venkatesh et al, 2012, 2003
	On average, other farmers I know think I should use SF technologies (2)	SI2	Beza et al., 2018; Faridi et al., 2020; Michels et al., 2020
	People I trust think I should use SF technologies (3)	SI3	Venkatesh et al, 2012, 2003
	In general, the organization (one or more) I belong to has/have supported the adoption of SF technologies (4)	SI4	Venkatesh et al, 2012, 2003
Facilitating Conditions - FC	*I think I have the necessary basic knowledge to adopt SF technologies*	FC1	Beza et al., 2018; Ronaghi and Forouharfar, 2020; Venkatesh et al., 2012, 2003
	I think I have the necessary resources (economic, technical,	FC2	Beza et al., 2018; Faridi et al., 2020;

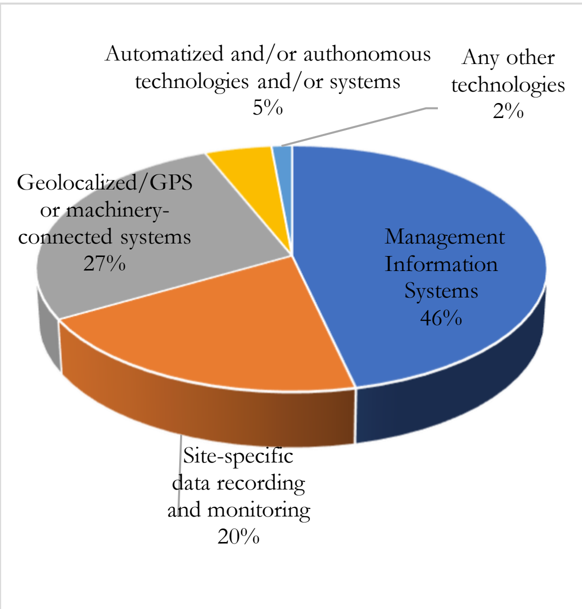
	infrastructural, etc.) to adopt SF technologies (2)		Ronaghi and Forouharfar, 2020; Venkatesh et al., 2003, 2012
	SF technologies are compatible with other technologies I already use (3)	FC3	Beza et al., 2018; Faridi et al., 2020; Ronaghi and Forouharfar, 2020; Venkatesh et al., 2003, 2012
	If I am in difficulty with the use of SF technologies, there are people (or a group of people) who would provide me with assistance and/or support (4)	FC4	Beza et al., 2018; Faridi et al., 2020; Ronaghi and Forouharfar, 2020; Venkatesh et al., 2003, 2012
Behavioral Intention – BI	*I plan to use or continue to use SF technologies in the future (1)*	BI1	Beza et al., 2018; Michels et al., 2020 Faridi et al., 2020; Ronaghi and Forouharfar, 2020; Venkatesh et al., 2003, 2012
	I intend to use or continue to use SF technologies (2)	BI2	Beza et al., 2018; Michels et al., 2020 Faridi et al., 2020; Ronaghi and Forouharfar, 2020; Venkatesh et al., 2003, 2012
	I always try to use SF technologies in the daily management of my company (3)	BI3	Beza et al., 2018; Ronaghi and Forouharfar, 2020; Venkatesh et al., 2012, 2003

A.3 Discussion – main implications from the study

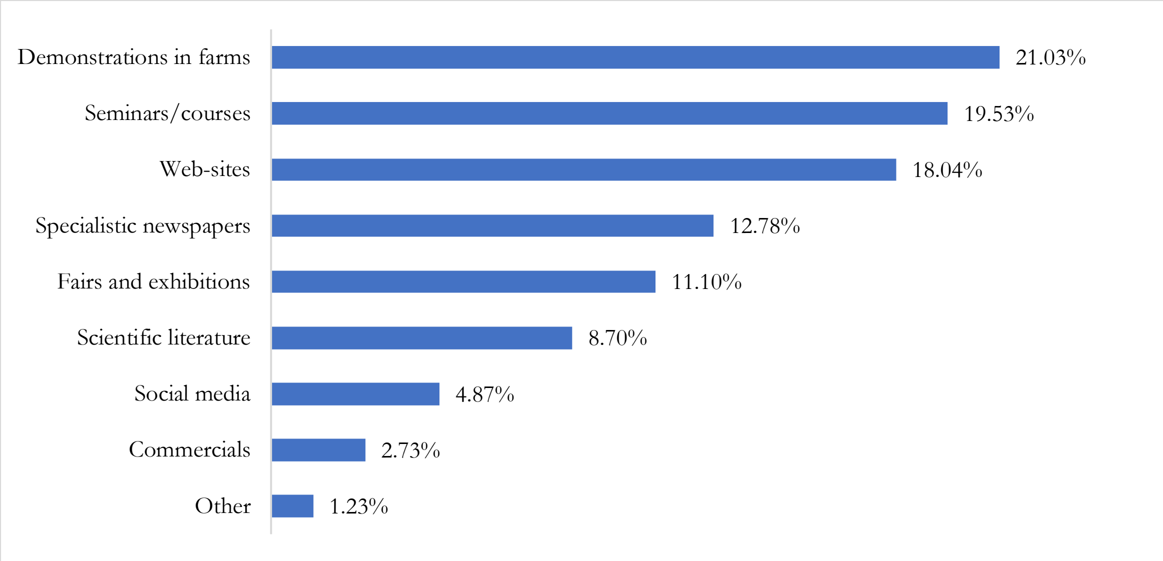
A.3.1 - Figure 10, main SFT adopted at Italian national level. Source: Smart Agrifood Observatory, 2020



A.3.2 - Figure 11, main SFT adopted. Source: author's elaborations on survey data.



A.3.3 - Figure 12, main information channels regarding SFT indicated by responding farmers. Source: author's elaboration on 1541 total responses obtained.



A.3.4 - Table 11, Support received in adoption process, Adopters vs Non adopters. Source: author's elaboration on survey data

		Did you adopt any of the SFT shown before?		
		Total	Yes	No
Did you receive support in the adoption of SFT from one or more organizations you belong?	Total Count (Answering)	557.0	312.0	245.0
	Si	108.0	86.0	22.0
		19.4%	27.6%	9.0%
	No	449.0	226.0	223.0
		80.6%	72.4%	91.0%

A.3.5 - Figure 13 - Main sources of information regarding SFT indicated by responding farmers. Source: author's elaboration on 1348 total responses obtained