Investing in rural people

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Contributions of information and communication technologies to food systems transformation

by
Tomaso Ceccarelli
Samyuktha Kannan
Francesco Cecchi
Sander Janssen

82 IFAD RESEARCH SERIES

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Contents

Abstract

Information and communication technologies (ICTs) are considered a possible game changer in boosting agricultural productivity, profitability, sustainability and resilience worldwide. Yet, more evidence is needed to understand the impact of current and potential digitally enabled solutions. This paper uses a food systems approach to review existing evidence, and discusses under which enabling conditions, for which segments of the rural population and with what timeline such solutions would achieve the desired outcomes. It finds that a shift towards serving (as much as possible) the whole farmer ecosystem, in the form of increased integration of solutions, is an emergent and yet unexplored impact pathway. At the same time, there is a clear and urgent need for a human capital agenda and ways to improve digital literacy – hence supporting transformation in the behavioural sphere – as well as for an analysis of the enabling environment to support the impact potential and inclusivity of digital solutions. The paper concludes by providing a comprehensive list of recommendations, hopefully useful for the IFAD Rural Development Report 2021, regarding the role that could be played by public institutions and policymakers in shaping future ICTs to enable inclusive and sustainable food systems transformation.

Keywords: information and communication technologies, digital solutions, food systems transformation, bundling, farmer ecosystem, low- and middle-income countries

1. Introduction

Information and communication technologies (ICTs) drive an accompanying digitalization process, which is considered a possible game changer in boosting agricultural productivity, profitability and resilience[1] to climate change (IFAD 2019), ultimately impacting favourably on food security and wealth creation in rural communities in low- and middle-income countries (LMICs). The introduction of ICT infrastructure, such as mobile networks and the internet (see annex 1), has already had a large impact on improving the lives of poor people in rural areas. Telephones, mobile phones and the internet have been shown to have a positive overall effect on agricultural productivity (Lio and Liu 2006), and producer and consumer welfare (Aker and Mbiti 2010). The expansion of mobile phone and internet coverage has been associated with improved prices for farmers (Goyal 2010), reduced price dispersion and wastage (Jensen 2007), and improved market participation (Aker and Fafchamps 2015).

ICTs and digital technologies also lend themselves to multiple use cases that can allow farmers to access their peers, potential buyers and sellers, welfare benefits and technical information or research (Aker et al. 2016). However, with rapid innovation and expansion of digital solutions in agriculture, it is crucial to synthesize research on impact and identify areas for improvement in programme, policy and institutional design such that negative trade-offs can be balanced. Importantly, evidence must be used to identify whether such technology increases the current digital divide or, on the contrary, serves positive transformations, particularly for the most vulnerable actors in the food system.

Given the wide range of ways in which ICTs and digital solutions affect agriculture, the food systems approach provides a useful way to outline the landscape of innovations and technologies, and collate their potential and actual impacts, as well as highlighting underlying mechanisms and trade-offs. This facilitates a comprehensive appraisal of the role of ICTs in supporting sustainable, resilient and inclusive food systems, and the framing of appropriate regulation and policy.

This paper uses the food systems approach as a starting point to create a logical framework (logframe) to map digital solutions, their potential impacts and underlying pathways in a systematic way. The logframe is used to map current evidence on impacts, focusing on three key food system outcomes (improved agricultural productivity, access to markets and climate risk resilience), ultimately resulting in improved income and welfare status of smallholders. An extensive literature review on outcomes, impacts, pathways and trade-offs of digital solutions is supported with three in-depth cases referring to the most promising use case, that of digital solutions combining multiple services, to examine the approach to integration and the main players involved, as well as possible positive transformative actions. Finally, the paper identifies areas where further evidence on impact and pathways is needed, interprets the analysis of the barriers to impact, and suggests ways to mitigate them through recommendations for institutions and policy.

2. Conceptual framework

The immense potential for digital solutions and underlying technologies to transform agricultural value chains, and the range of their application in the food system, is recognized by key stakeholders and institutions worldwide. Nevertheless, evidence on impacts, and frameworks to critically analyse performance and potential, are relatively less formalized (Mthoko and Khene 2017). To better understand and represent the mechanisms by which such solutions affect value chains, this study developed a simplified logframe, commonly used in programme evaluation literature, as a guide for its analysis. This uses the system-level perspective of the food systems approach, which takes a holistic approach to the food system, with a focus on the goals of increasing the supply of safe and healthy food within

[1] Resilience refers primarily to climate change. However, ICT plays an important role in other slow- and fast-onset hazards that can lead at times to concurrent and cascading crises. This applies also to the COVID-19 pandemic, where accelerated digitalization processes are being promoted, creating opportunities but also potential risks of a further digital divide.

environmental limits (including those due to climate change) and in an inclusive way (van Berkum et al. 2018).

2.1 ICT and digitalization in the food systems approach

The High Level Panel of Experts on Food Security and Nutrition Framework (HLPE 2017) describes food systems as consisting of three aspects: drivers, components and outcomes (figure 1). In this framework, innovation, technology and infrastructure are considered drivers of food systems transformation with the potential to affect all the components of a food system, including food value chains, food environments and consumer behaviour. ICTs and digitalization embody the characteristics of such a driver of food systems transformation. For example, digital solutions that enable the retrieval and dissemination of relevant agronomic, environmental and market data to smallholder farmers, such as early warning, agro-advisory and price information systems, can transform the food value chain by increasing productivity, resource efficiency and profitability. Solutions that provide market access and traceability by better connecting buyers, sellers and producers, such as through digital marketplaces and end-to-end supply chain management solutions, can drive more responsive and safe food environments. Improved connectivity, access to information and peer-to-peer sharing provided by ICTs such as mobile phones, radio and the internet, can also influence the distribution of rents from food production, as well as consumer behaviour. In addition, digital applications in agriculture catalyse the other drivers (political, economic and social) of food systems transformation.

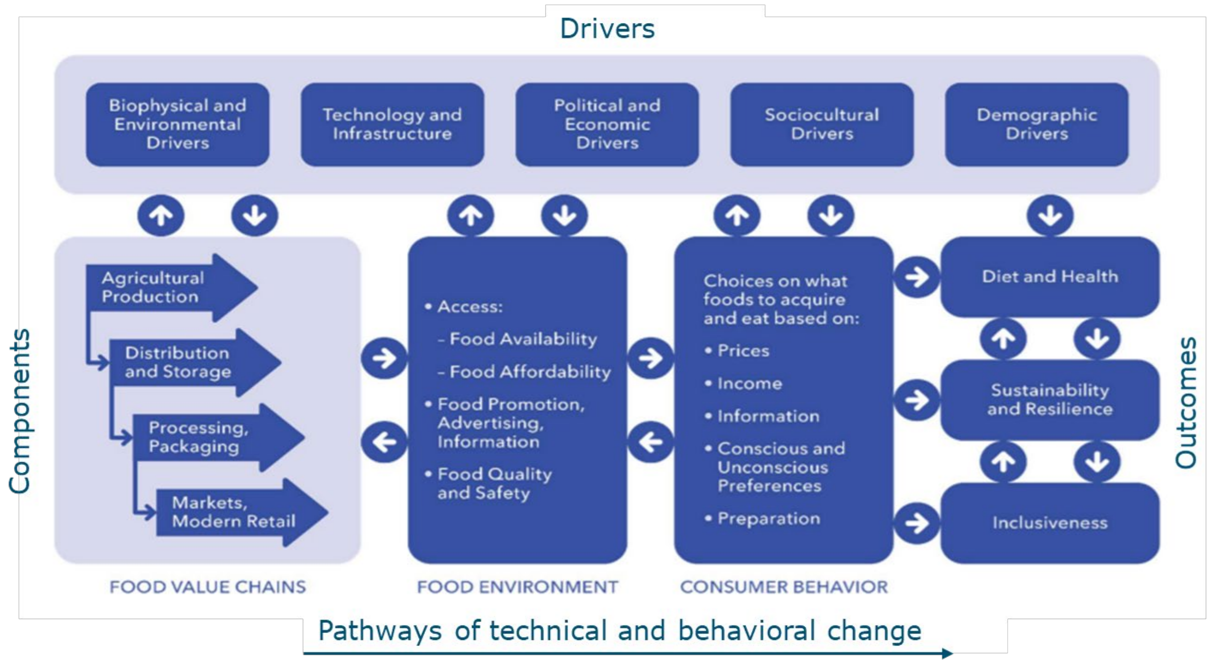

Figure 1: Food systems framework

Source: Adapted from HLPE (2017).

For the purposes of this study, the focus is on the potential for ICTs and digitalization to transform the food value chain component of the food system consisting of agricultural production and marketing (ibid.). The value chain transformation is characterized through three broad outcomes: productivity, climate resilience and profitability, with the ultimate goal of improving the economic and social conditions of rural communities.

2.2 Digital solutions for value chain transformation: A logical framework

A logframe allows for an articulation of hypothesized effects and makes possible a critical appraisal of evidence on impacts (Team Technologies Middleburg Virginia 2005). As depicted in figure 2, the proposed logframe provides an overview of inputs, transformation pathways, intermediate outcomes, impacts and their possible trade-offs and spillover effects, focusing on mapping direct relationships while acknowledging the position of value chains in the larger food systems framework.

2.2.1 Inputs

Digital technologies form solutions, which can be clustered based on their primary use cases (see table 1), as identified in The Digitalisation of African Agriculture Report 2018–2019 (Tsan et al. 2019). The use cases are listed both individually and as bundled solutions to denote platforms that offer a combination of digital products and services. These are regarded as inputs or drivers in the transformation pathways. Use cases and digital solutions require an enabling environment, including governance and regulatory frameworks, infrastructures and institutions to warrant their application in agriculture and food system-related use cases (IFAD 2019; ITU and UNESCO 2019).

2.2.2 Outputs

Solutions result in a number of direct outputs, such as pest management alerts and advisory delivered to farmers through short message service (SMS) and interactive voice response. Another example is the case of financial services, where solutions generate systems in support of agricultural credit scoring. Given their very large number, outputs are not listed in detail in the logframe scheme.

2.2.3 Pathways

Potential pathways can be traced through which solutions affect the food value chain, using key indicators of technical and behaviour change (HLPE 2017). The pathways are informed by the review of additional reports (listed in annex 2). Pathways depicted in the logframe include improved knowledge, learning and capacity (Nakasone et al. 2014; Cole and Fernando 2012; Deichmann et al. 2016); farm management (Deichmann et al. 2016); adoption of technology and best practices (Nakasone et al. 2014; Deichmann et al. 2016); natural resource management (GIZ 2018); diversification and value addition (UNCTAD 2019); knowledge of prices and markets (Nakasone et al. 2014; Deichmann et al. 2016); transparency in value chains (WEF 2019); and transaction costs (Deichmann et al. 2016).

2.2.4 Intermediate outcomes

These consist of the three aspects of value chain development outlined in this study: productivity, profitability and resilience. Each of these aspects represents the multiple outcomes that define it. Productivity includes improvements to agricultural input use, production, yields and incomes; profitability includes access to finance and input and output markets; and climate resilience includes diversification and risk coping.

2.2.5 Impacts

The final impact is characterized as the effects of the transformation of agricultural value chains, recognizing the interplay of other food system elements (drivers, components and outcomes) as depicted in HLPE (2017) and in the guiding framework of the IFAD Rural Development Report 2021. Intermediate outcomes of desired transformation pathways jointly impact poverty reduction, employment, food security and wealth creation in rural communities, making their food value chains more sustainable. Finally, additional potential impacts are considered, such as social inclusion, nutrition and environmental effects, and their trade-offs vis-à-vis the main impacts.

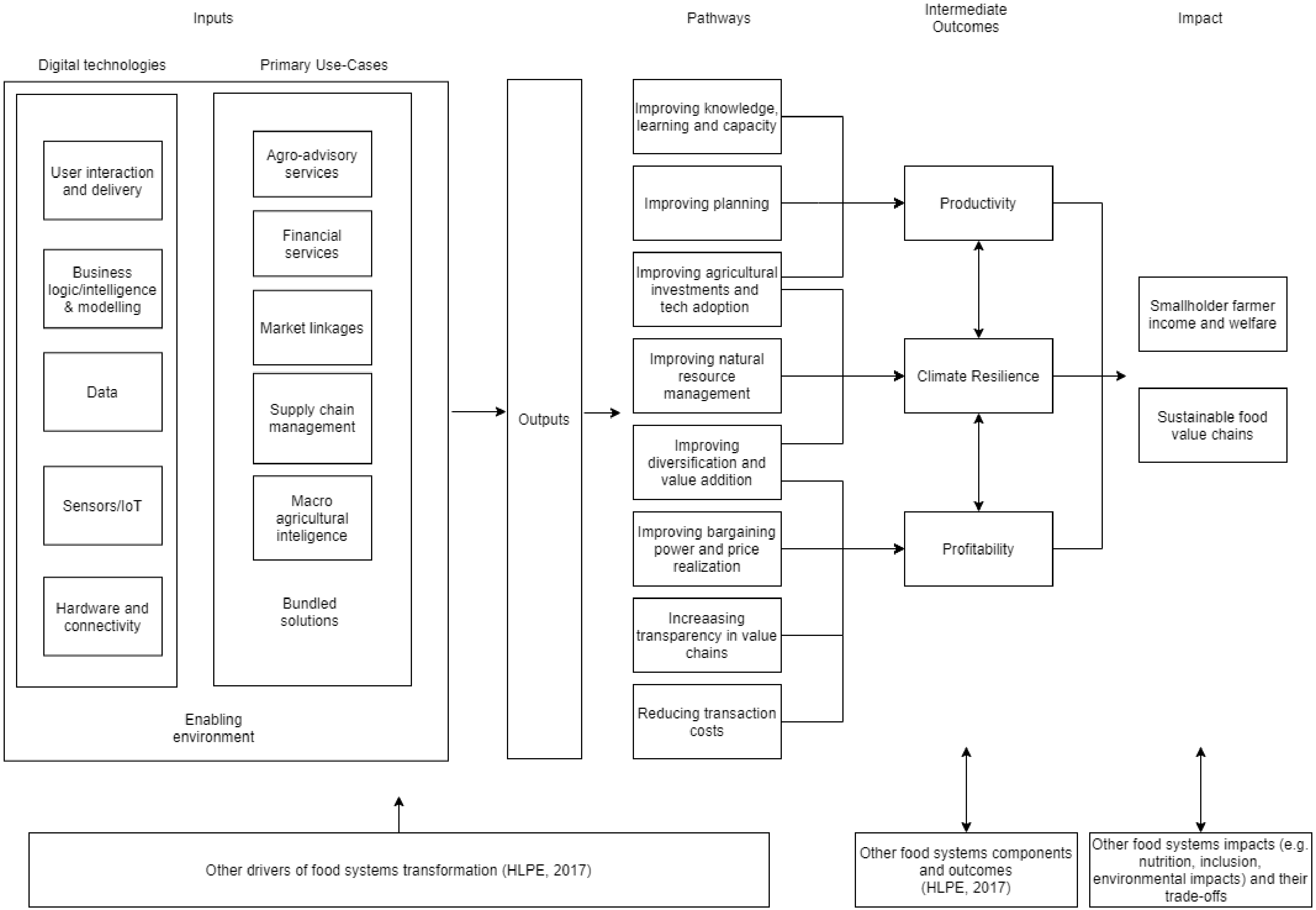

Figure 2: Digital solutions and technologies for value chain transformation

Table 1
Overview of use cases and solutions in food value chains

Use cases	*Overview of main digital solutions*
Advisory and information services	Diagnosis of soil/plant/livestock health
	Dissemination of information on best practices
	Dissemination of information on conservation practices
	Participatory learning platforms
	Precision advisory
	Forecasting and early warning systems
	Planning and monitoring platforms
	Budgeting and financial management
	Farmer cooperatives and organization management
Financial services	Fundraising platforms
	Micro-banking
	Crop and livestock insurance
Market linkages	Input supply information systems
	Input marketplaces
	Shared machinery services
	Off-take market and price information systems
	Linkage to buyers and agribusinesses
	Off-take marketplaces and commodity trading
Supply chain management	Access to transportation and storage
	Quality assurance, compliance and tracing
	Transactions and payments
Macro agricultural intelligence	Weather and climate observatories
	Public sector programme monitoring and evaluation
	Extension system management
Bundled solutions	End-to-end value chain integration
	Advisories with input linkages
	Credit assessment with farm advisory
	Super-platforms

Source: Authors’ construction based on review.

2.3 Use cases and digital solutions

Using the terminologies provided in Tsan et al. (2019), the specific applications of ICTs in the food value chain are denoted as digital solutions and grouped under six broad use cases: (i) advisory and information services; (ii) market linkages; (iii) supply chain management; (iv) financial services; (v) macro-agricultural intelligence; and (vi) encompassing integrated solutions. The latter comprises bundled services and what the same report refers to as “super-platforms,” although there are important differences that will be elaborated further in this paper. The term “use case” refers to components of the food value chain in which a technology can be used, while “solutions” refer to digital products or services within the use case, differentiated by their features, objectives and users. For example, the use case “advisory and information services” consists of both solutions that provide generic information at an aggregated level, and those that aim to reach individual farmers and fields for precision farming. The overview presented in table 1 is intended to provide an extensive enumeration (see annex 2 for the sources). The list is restricted to include only those digital solutions that are suited – directly or indirectly – to smallholder farming and where there is at least one working example from an LMIC.

3. Methods

Impacts and potential for ICTs and digital solutions in the transformation of food systems are analysed in two ways: (i) through a review of published literature on impacts and impact pathways; and (ii) through an in-depth analysis of three chosen case studies.

3.1 Literature review on impacts

Available empirical evidence is reviewed on the effects of solutions for each of the five primary use cases identified in section 2.3 on pathways, intermediate outcomes, impacts and their trade-offs in food value chains. This has the aim of understanding the current knowledge base and identifying areas for further research and development. The review is restricted to include evidence that is peer-reviewed, independently evaluated or follows a set research design, and measures impacts on one or more quantitative parameters pertaining to productivity, profitability or climate resilience in smallholder farmers. Emphasis is placed on collating evidence on smallholder farmers in developing countries. The review is by no means comprehensive and is intended to highlight solutions with strong evidence of success, as well as solutions requiring more conclusive research. Key lessons from literature on the direction of effects (positive/negative) and the context and determinants of success or failure are highlighted in each use case, with the insights used to validate the logframe and identify areas for further research and evidence-building. Some insights into reasons for weak or heterogeneous impacts are explored where relevant.

3.2 In-depth analysis of case studies

A number of case studies have been selected from the broader range of examples in the literature and evidence review as a means to gain greater insight and validate specific aspects of the study. The more in-depth cases were selected as successful examples, at least in terms of outreach, that are developing integrated solutions. The selection was based on contrasting perspectives in terms of the degree of integration (from limited integration to greater coverage of more use cases), type of solutions offered (bundled solutions or super-platforms), main players involved (government or the private sector), and the geographies and scales targeted. An analysis of the features of such solutions (namely, the underlying technologies) and of relevant contextual elements was carried out, including the actors involved and their roles, outcomes and users targeted, technical infrastructure and human capital, policy and regulatory environment, business and sustainability models, potential and constraints for scaling, as well as possible transformative actions. The expected result is an evaluation of the potential of specific solutions leading to desired value chain system transformations, their impacts and trade-offs as highlighted in the logframe.

To address the initial research questions, an evaluation framework was developed, which has been applied to the case studies. This framework, further elaborated in the in-depth cases, starts with the specification of the digital solution and the underlying technological components.[2] It then formulates questions such as: which food systems outcomes are targeted by the solution, and how? For example, is the advisory of the general purpose type or supporting customized users for precision farming? Does it serve the most vulnerable communities at large (does it consider delivery mechanisms and farming practices that are adapted to smallholders and farmers who are relatively less endowed? Is it sufficiently attentive to gender equality and to disadvantaged groups)? Does it have the potential to scale from the perspective of the technologies themselves (based on their readiness level), the technical and human capacity, the institutional and policy environment, and its financial sustainability? Does it yield to negative impacts or positive synergies? What are the trade-offs and spillover effects to be considered? What are possible transformative actions to be taken, and are there any mitigation strategies and tools that can be used in case of negative impacts?

4. Evidence review

There is a substantial body of qualitative and quantitative social science literature on the impacts of ICTs and digital solutions on productivity, climate resilience and profitability of smallholder agriculture. The literature review is organized around five use cases: (i) advisory and information services; (ii) financial services; (iii) market links; (iv) supply chain management; and (v) macro-agricultural intelligence. The analysis is completed with a sixth use case, on integrated solutions, either through service bundling or super-platforms, following the definition originally formulated by Mercy Corps AgriFin. A summary of the reviewed evidence and gaps is provided in annex 3.

4.1 Use case 1: Advisory and information services

Advisory and information services on weather, farming practices and new technologies are among the earliest and most extensively studied applications of digital technology and ICTs in agriculture (see Nakasone et al. 2014; Baumüller 2018; Deichmann et al. 2016; Fabregas et al. 2019 for extensive reviews). Developing countries with low productivity, low rates of technology adoption and overextended public extension systems can benefit from the proliferation of mobile phones in rural areas. Advisories provided through ICTs can improve agricultural productivity by reducing both information deficiencies and the costs of accessing information regarding new technologies or best practices (Jack 2013). Aker and Ksoll (2016) find positive impacts of an adult digital literacy programme in Niger on crop diversity, suggesting that informed and connected adults can access information on their own accord. Cieslik et al. (2021), through a framed experiment conducted in Ethiopia, found that ICTs improve cooperation between farmers on action against public bads such as crop disease.

Several studies conducted in the early 2010s showethat ICTs also enabled the provision of faster, more relevant and better-quality advisories (Camacho and Conover 2011; Fu and Akter 2016); allowed for accountability of extension agents (Cole and Fernando 2012); reduced the costs of advisory provision (Aker 2011; Nakasone et al. 2014); and improved sharing of information in farmers' social networks (Aker 2011). The evidence of impacts on yields and farming practices, however, is mixed. Evaluations of SMS-based weather and crop advisory services find no impacts on cultivation practices or weather-related harvest losses in certain contexts (Fafchamps and Minten 2012), and modest impacts on awareness and knowledge of extension messages (Fu and Akter 2016; Mittal 2016); reduction in losses (Camacho and Conover 2011); and improvements in yields in others (Gandhi et al. 2009). Further, many of the early results relied on knowledge tests and self-reported changes in behaviour and yields, both of which raise concerns on the consistency of results and overestimation of impacts (Fabregas, Kremer and Schilbach 2019).

[2] Ideally, the framework should have started from a development challenge, flowing naturally into the digital solutions available to address it. However, given that each challenge has multiple digital options available, and that every digital solution can be used to address a wide range of challenges, this proved unfeasible. Forced to dropone of the two sides, the authors opted to keep the analysis focused on the tools, which are ultimately the subject of this paper.

Recent experimental evaluations focused on measuring behaviour changes and yields objectively have found more promising results. Meta-analyses compiled by Fabregas et al. (2019) find that providing mobile-based advisory on average improves the odds of farmers purchasing the recommended input by 22 per cent, increases yields by approximately 4 per cent and provides a return on investment of up to 10 times. A comparison between mobile advisories delivered directly to farmers and mediated through in-person extension agents reveals that both are equally effective in improving yields. Results do, however, vary across contexts, in magnitude and statistical significance, and could have heterogeneous impacts among farmers with different characteristics and in different advisory modalities (Fabregas, Kremer and Schilbach 2019). Evidence is also progressively being built around the impacts of more sophisticated and interactive advisory programmes. Early research suggests that personalization of advisories based on ground-level data has improved the adoption of new crops or technologies, input use and yields (Van Campenhout et al. 2017; Cole and Fernando 2018; Gandhi et al. 2009; Larochelle et al. 2019). Case studies, such as those conducted by Groupe Speciale Mobile Association (GSMA 2015) and the World Bank Group (2016) reveal early results from monitoring and evaluations on the user characteristics, uptake, costs and effects of these programmes.

Despite being the most extensively studied use case of mobile and digital technologies, there are considerable gaps in our knowledge on digitized advisory and information services in smallholder agriculture that merit further research. In contexts where mobile-based advisory has not been successful, sufficient empirical research is yet to be directed towards identifying technical, behavioural or socio-economic reasons for limited impact, as well as solutions that can potentially overcome these challenges. Moreover, for a field with rapid innovation and active public and private participation, rigorous evaluations on the impacts and cost-effectiveness of more advanced digital advisory applications are not yet readily available. This includes impacts of customization through field-level satellite and ground data, participatory platforms and social media, the use of multimedia in advisory or applications leveraging database management, social media and artificial intelligence, to provide diagnosis and planning support. Further evidence on trade-offs, inclusivity and sustainability of these programmes also becomes increasingly pertinent with the development of sophisticated technology and will be beneficial in understanding their true potential and cost-effectiveness. Although digital advisories could potentially remove the biases associated with in-person advisories (Benyishay and Mobarak 2019; Fu and Akter 2016), there is reason to believe that programmes, particularly those that rely on expensive devices, requiring heavy engagement and complex actions from farmers, may favour richer, more educated farmers (Cole and Fernando 2018).

4.2 Use case 2: Financial services

Lack of connectivity and information in rural areas makes it difficult for banking and insurance service providers to assess and manage risk, and thereby hinders the supply of formal finance to farmers (Armendáriz and Morduch 2010). While some innovative financial instruments such as group credit and index insurance have been successful in meeting this challenge (Banerjee 2013; Cole and Wentao 2017), digital tools can potentially play a role in reducing transaction costs associated with financing farm operations. In this regard, there has been an increasing role for remote sensing, analytics and big data solutions to meet the data requirements of financial service providers (Tsan et al. 2019). However, business-to-consumer digital tools and ICTs are also uniquely positioned to improve the engagement between farmers and financial service providers, improve transparency and facilitate transactions with more direct impacts on agricultural outcomes (World Bank Group 2019a). The impacts of improved financial access on smallholder farmers' input use, income and consumption have been discussed in numerous contexts with mixed results (de Janvry et al. 2017). While improved access to credit and savings has been associated with higher agricultural investments, input use and farm incomes, impacts have sometimes been diminished due to low take-up (Beaman et al. 2014; Crépon et al. 2015), uninsured risk (Karlan et al. 2014), behavioural biases (Duflo et al. 2011) or poor market access (Beaman, Karlan and Thuysbaert 2014; Carter et al. 2016).

Availing crop insurance improves agricultural investments and encourages diversification into high-risk high-return crops or livestock (Cole et al. 2014; Mobarak and Rosenzweig 2013), but such programmes have also suffered low trust and take-up (Cole and Wentao 2017). The best-developed digital solution in the financial services use case is mobile payments. Mobile money and payment platforms that emulate the

M-pesa model make it easy and cost-effective for farmers to send and receive remittances (Jack and Suri 2011). Baumüller (2018) analyses three studies on mobile payments and notes that while money withdrawn through e-wallets is commonly spent on agriculture (by 60 to 70 per cent of farmers), payments through e-wallets for goods and services is far less common. While it remains challenging for e-wallets to reach their full potential and an increased scale, the studies show that having an e-wallet is associated with increased input use, income, market access and opportunities for off-farm income, reiterating their usefulness in improving financial access. However, the studies presented here demonstrate some limited evidence, and negative cases might not be reported. Mobile payments have also provided an ideal platform to bundle credit and savings services, encourage deposit and repayment commitments and monitor risk. For example, a mobile money-based savings scheme in Mozambique proved successful in improving savings and encouraging input use (Batista and Vicente 2020). Digital tools are also useful in improving the accuracy of crop insurance products and their engagement with farmers (Ceballos et al. 2019).

Several organizations are taking the lead in compiling early lessons from digitally enabled financial services. Case studies by the Consultative Group to Assist the Poor (CGAP) (Grossman and Tarazi 2014), IFC and Mastercard Foundation (n.d.) and Malabo Montpellier Panel (2019) have reported the success of digital financial access solutions in improving insurance, assessing creditworthiness and raising equity for farm operations. However, the quantification of long-term effects on smallholder farmer output and incomes will be necessary to evaluate their sustainability, feasibility of scaling up, and cost-effectiveness. While the evidence base for farmer-oriented digital solutions in finance is still emerging, the largest impacts of digital services are likely to be behind the scenes, and there is encouraging evidence that they have already had an impact on measures of financial inclusion, particularly in Africa (Demirgüç-Kunt et al. 2017). Despite the considerable potential for digital services to address common difficulties in rural finance such as high costs, low uptake, lack of information on creditworthiness and high basis risk, their impacts are relatively understudied. In economic literature, the impacts of savings and credit schemes are widely studied (Banerjee 2013); although access to finance improves investment in agriculture, there has been poor translation of these investments into improved yields or income from agriculture, suggesting that there may be other barriers at play (J-PAL 2018, 2019). This experience provides some indication that digitally aided financial inclusion may also yield muted impacts, unless resources, knowledge and behavioural barriers are also addressed.

4.3 Use case 3: Market links

Digitalization and ICTs that improve input and output market linkages for farmers and other actors along the value chain have direct implications for farmers' profits and incomes, since they can help increase revenues and reduce costs. ICTs can address agricultural market imperfections by providing access to information on supply, demand or market prices, thereby improving farmers' bargaining power or introducing opportunities for arbitrage (Aker and Ksoll 2016). In the long run, farmers can benefit more substantially from market information by improving their productivity, altering their cropping patterns and reallocating resources to meet demand (Nakasone et al. 2014). Benefits extend to consumers too, in the form of stable prices and supply, thereby improving both producer and consumer welfare. With their inherent ability to improve coordination among market players, the very introduction of ICT infrastructure, such as mobile phones and the internet, has had a positive and well-documented impact on reducing price dispersion and improving farmgate prices in several countries. One of the earliest studies on ICTs and off-take markets (Jensen 2007) showed that the introduction of mobile phones reduced price spread and wastage of 300 fishing units spanning 15 fish off-take markets in rural south India, and improved profits by 8 per cent. Multiple studies since then have established positive impacts of ICTs or mobile coverage on price realization across several models of price-setting, such as those with and without middlemen and in different levels of competition (Nakasone et al. 2014; also see Deichmann et al. 2016; World Bank Group 2017; Fabregas, Kremer and Schilbach 2019 for a more comprehensive review).

Programmes that gather, analyse and provide input and off-take market information via ICTs to farmers attempt to improve market efficiency and transparency more directly (e.g. price information systems and online marketplaces). However, their effectiveness and impacts are either not yet rigorously researched, as in the case of programmes linking farmers to input sellers, or have found only moderate success, as in the case of programmes linking farmers to buyers. Marketplaces for agricultural inputs are relatively new and small in scale (Tsan et al. 2019) and, as a result, have not been evaluated extensively for impacts on productivity or costs. There is some encouraging evidence, however, that ICTs can be used by farmers to monitor and improve input delivery in contract farming arrangements (Casaburi and Kremer 2019) and redeem input subsidies from the government in Nigeria (Uduji et al. 2019). For mechanical inputs, rental services such as Hello Tractor and Trringo have reported large-scale uptake of over a million farmers, although case studies indicate that they face challenges from low smartphone ownership, little trust in online transactions, and difficulties in basic infrastructure hampering input delivery (Daum et al. 2020). An early experiment in matching agricultural labour with farmers was also not well used by labourers due to a lack of trust in work contracts received over the phone (Balasuriya and de Silva 2011). Evaluations of programmes that provide price and market information through mobile phones have seen mixed success. While Goyal, (2010), Nakasone (2013) and Courtois and Subervie (2014) found large improvements in farm prices, several authors (Camacho and Conover, 2011; Fafchamps and Minten, 2012; Mitra et al., 2018) did not. In cases where market information systems have failed to fetch higher prices, it has been found that low levels of usage (Fafchamps and Minten 2012), large transaction costs (Fafchamps and Minten 2012; Mitra et al. 2018), lack of alternative markets (Islam and Grönlund 2010) and interlinked contracts – for example, for renting land, borrowing money and selling to the same individual (Lokanathan et al. 2011; Molony 2008) – can inhibit impacts.

Interestingly, off-take market price information systems have influenced farmers’ decisions on crop choice, and harvest and sale timings (Baumüller 2018). The impacts of market and price information systems have been evaluated with mixed results, and evidence suggests that markets may be plagued by multiple barriers to trade and imperfections other than information asymmetry, thereby limiting the impact of these types of digital solutions, as well as those linking farmers to buyers and agribusiness. While input-side interventions seem more promising, a lot more evidence is needed to assess the viability and effectiveness of input supply information systems, marketplaces and shared machinery, especially as smartphone ownership and mobile payments increase in developing countries. Interesting avenues for further study in input interventions include the effects of providing information on input quality on adulteration and adoption (Ashour et al. 2016; Fabregas, Kremer and Schilbach 2019). End-to-end value chain solutions that are integrating market linkages with financial payments or logistics are better placed to address multiple market failures and achieve impacts on profitability. Some large-scale private sector players, such as Safaricom’s Digifarm and One Acre Fund, are already exploring these avenues and may provide an excellent opportunity to study the effect of market linkages. Building comprehensive evidence around end-to-end solutions will be valuable in assessing their cost-effectiveness and guiding future investments.

4.4 Use case 4: Supply chain management

As indicated in the previous section, market linkages and price information are rarely sufficient to improve farm profitability. Farmers face several additional barriers to trade, such as significant transaction costs to cater to demand in faraway or global markets, as well as the cost of transportation to reach these markets while maintaining the quality and safety of produce (Dorosh et al. 2010). Digital and ICT tools can enable better coordination across the supply chain by fostering transparent relationships between farmers and agribusinesses or end-users, facilitating better distribution of inputs and produce, and improving access to transport and storage facilities (Deichmann et al. 2016). In this use case too, several business-to-business solutions abound, such as enterprise resource planning software, tracking and logistics management, etc. (see Tsan et al. 2019 for an overview). Farmer-oriented solutions have also emerged. An open point for discussion is whether such solutions would only benefit the more commercially oriented and larger-scale farmers, or also have a role to play with the most marginalized. Case studies indicate that ICTs have achieved some success in connecting farmers to transport operators in Zambia (Deichmann et al. 2016), coordinating supply and transport in contract farming arrangements (Malabo Montpellier Panel 2019), and improving traceability and certification (World Bank Group 2019a). However, since supply chain management solutions for smallholders are relatively new, quantitative evidence remains to be built on their effectiveness in reducing post-harvest losses and improving smallholder profitability.

4.5 Use case 5: Macro-agricultural intelligence

Data arising from or aggregated through digital technologies and ICTs ultimately form an invaluable resource for governments, businesses and non-profit institutions to track programme implementation and effects, monitor risks and evaluate policy. Macro-agricultural intelligence can potentially lead to systemic improvements and efficient investments (Tsan et al. 2019), with indirect effects for smallholder farmer productivity, profitability and climate resilience. The experiences of different countries in using agricultural intelligence to improve public policy have been recorded in the report of the Malabo Montpellier Panel (2019). However, aside from qualitative accounts, the impact of improved programme implementation using big data on smallholders is not easily quantified. Evaluations of mHealth applications in improving the delivery of public health and nutrition programmes by organizations such as the World Bank (Lee et al. 2017) provide an example of how investments in digital data collection and analytics can be evaluated for cost-effectiveness. Altogether, it was not possible to provide positive evidence in annex 3.

4.6 Use case 6: Integrated use cases (bundled solutions and super-platforms)

Solutions that integrate some or even all the use cases given above represent an emerging case likely to grow substantially in the next few years, particularly in LMICs. Aside from the increased upfront complexity and initial cost of setting them up, such solutions are attractive to many actors, as, at a minimum, they digitally integrate and formalize value chains (Tsan et al. 2019).

The idea of integrating individual solutions to enhance impacts and economics is not new. For instance, eight years ago the Mercy Corps AgriFin Accelerate programme started packaging together finance and advisory services in a few pilots, then scaled out in a number of countries, also embracing commercial concepts exemplified by Safaricom's DigiFarm and introducing access to agricultural inputs, insurance, last-mile logistics and market linkages. One Acre Fund is another example, which had more than 800,000 farmer clients in 2018 for its approach to integration. It includes digital agent field force management tools, agent-intermediated input market linkages for non-commercial smallholder farmer value chains, digital farmer registrations, digitally enabled monitoring and evaluation, and mobile input loan repayments, among other digitalization initiatives. What is new are the improved and still evolving ideas about how to make such solutions work together. Integrated solutions can have different initiators and different evolutions of the original business model, though mostly for individual solutions. Several Fintech innovators, for instance, have moved from digital credit products integrating end-to-end market linkage models and advisory products. Many (e.g. Apollo Agriculture, Musoni microfinance and Tulaa) started operating in Kenya and Uganda (Akello Banker), with prospects of scaling activities in other countries. Also, digital market linkages are a typical entry point for such solutions, and several players are exploring this type of model from the digital advisory angle (e.g. the market-led, user-owned ICT for agriculture-enabled information service known as MUIIS in Uganda).

Whatever the entry point, the trajectory towards service integration is similar and aims to unlock maximum impact on smallholder farmers and economic attractiveness for digitalization for agriculture (D4Ag) intermediaries. A categorization of solutions can be made based on the current promotors (the player type), the number of use cases provided (coverage), the type or depth of each service (e.g. more generic or precision farming advisory) and the approach to integration, from bundling of services (i.e. through multi-player partnerships) to the so called super-platforms deploying all services in-house. The latter is yet another family of fast-growing digital solutions, which is related to this use case. Super-platforms, in the definition originally formulated by Mercy Corps AgriFin, deliver a fully integrated digital value proposition to smallholder farmers and other agricultural value chain intermediaries. In this case, it is usually one organization (e.g. a commercial enterprise with e-commerce), often combined with payments, that is central to and entirely owns the system. Examples range from new market linkage players such as Twiga Foods in Kenya to e-commerce leaders such as Rural Taobao in China promoted by Alibaba (Luo and Niu 2019), which is potentially expanding across Asia and to Africa. As illustrated by Tsan et al. (2019), the range of players that have built, are building or may aspire to build such super-platforms is very wide, including global digital e-commerce players, financial institutions, mobile network operators, agribusinesses, market linkage specialists, and government- and donor-led public-private partnerships.

Integrated solutions have the potential to address the entire ecosystem of a farmer, which is seen as a key element for increasing farmers' productivity and wealth. Nevertheless, the impacts and economics of such combined solutions are relatively understudied compared to other digital use cases. Rigorous evaluations of integrated solutions are both analytically and operationally challenging. This difficulty is reflected in annex 3 (where it was not possible to provide sufficient supporting evidence). This represents a major gap that will need to be addressed in future research (see sections 5 and 6).

5. In-depth cases

The in-depth analysis is based on three cases, which fall into the category of integrated solutions (as discussed in section 4.6) and are regarded by many observers as successful, at least in terms of user outreach. They were purposely selected as contrasting cases from the following interconnected perspectives: (i) the degree of integration, ranging from limited to ample coverage of multiple services; (ii) the approach to integration offered (i.e. bundled solutions with multi-player partnerships or super-platforms with a commercial enterprise or government organization at the core); and (iii) the main players involved – i.e. government- or private sector-led (the latter either being local D4Ag innovators or global players, e.g. those involved in e-commerce). The geographies also vary and include Eastern and West Africa, as well as Asia. The evaluation used information gathered from interviews with people involved directly in the services and from web resources.

5.1 The 8028 farmer hotline in Ethiopia

This solution by the Agricultural Transformation Agency (ATA), which is part of the Federal Ministry of Agriculture in Ethiopia, is an example of agro-advisory at scale, although with limited integration of other services. It is based on SMS and interactive voice response technologies and call centre support as the user interaction and delivery channel, and has achieved 4 million registered farmers and other users in the country, making it the single largest D4Ag solution in Africa.

It has agriculture sector-specific data at the back end, which are accessed by experts who provide the advice, supported by some analytics. It, therefore, addresses the productivity output through the dissemination of advice generated by the extension directorate of the ministry, complemented by ad hoc work by ATA. The advisory service can potentially also address climate resilience through climate-smart technologies and recommendations. However, the information is not sufficiently downscaled, and advice generated by the ministry mostly targets "better farmers." Attention to the most disadvantaged segments of rural producers is an aspect that the ministry intends to strengthen. Therefore, the gap between eventual dissemination and adoption, especially for disadvantaged farmers, is important.

Does the solution have the potential to scale up further? Technically speaking, the answer is affirmative, as it is supported by Ethio Telecom for the bulk delivery of SMS, and by ATA for running the platform and generating the content. However, the limits in the input data also limit the level of possible customization of the service. Institutionally the service is backed strongly by the Government of Ethiopia, even though the expected transfer of the service from ATA to the ministry causes some uncertainties in the sustainability of the service from the technical viewpoint. The major impediment, however, seems to be financial sustainability, as the system is currently totally subsidized by donors and Ethio Telecom. This makes the project's existence over time intertwined with Ethio Telecom's willingness to continue to subsidize it. It also limits the scope for further scaling, unless viable monetization strategies are identified and implemented. Possible transformative actions (pathways) include, on the technical side, the generation of customized advisory (implying generation of downscaled and fit-for-purpose data such as weather forecasts, soil fertility, crop requirements and management practices), intended to address specific groups/typologies of smallholders. This, coupled with stronger feedback mechanisms (to promote greater ownership of the system by users) and analytics (based on the different sources of big data generated, potentially integrated with other sources such as remote and proximal sensing, and crowdsourced information from extension workers and farmers), would promote adoption by the smallholder farmer communities targeted. On the financial side, the solution in place could be used for combining other important services for addressing other sides of the farmers' ecosystem, such as price information and information on access to credit and insurance. Apart from generating a positive ecosystem for the farmers, this could lead to alternative business models, ensuring sustainability beyond or together with public, private and donor funding. There are plans to accomplish this in the future. For example, as part of the recently launched Digital Green advisory data ecosystem consortium in Ethiopia, funded by the Bill and Melinda Gates Foundation, ATA will be looking at opportunities to integrate or link this with the 8028 hotline, digital credit and payments (the eVoucher system) in potential partnership with Ethio Telecom. Further negative impacts may arise in the case of a strengthened feedback system from the farmers, in terms of data ownership and sharing, especially in the case of commercial services bundled with the current advisory services.

5.2 Farmerline, Ghana

Farmerline is a social software company based in Ghana and operating in 16 African countries with 70 partner organizations. Its mission is to help transform farmers into profitable and successful entrepreneurs, also raising the visibility of all value chain actors. Its digital solutions are now reaching over 500,000 farmers and comprise bundled solutions (offered as a business-to-farmer model in Ghana only, reaching 40,000 farmers) and applications (e.g. certification tools) offered as business-to-business in the form of software as a service. In Ghana, a portfolio of services is offered, including high-quality seed provision (delivered at the farm gate), links connecting farmers with food manufacturers ensuring a reliable market outlet, access to competitive agricultural credit (including credit scoring), and free training throughout the crop cycle on farming, food nutrition and safety, and business. Through the Farmerline platform, bundled services connect farm input companies, financial institutions, food brands, government actors and donor organizations. Farmers also receive free voice messages (in different local languages) on their mobile phones with information on agro-practices, weather forecasts and prices. COVID-19-related information was added more recently.

Over seven years of operations, Farmerline observed that farmers are not willing to pay for specific information, hence the need for bundling. Moreover, all farmers in the network are registered and given digital identity cards, which they use for all transactions with Farmerline. Farmers' data are owned by the farmers. The bundling gives a strong value to the entire service portfolio, but technology alone is not sufficient and must be complemented by services provided in person, and accompanied by behaviour changes. Hence the emphasis given to the complementary field force (extension, etc.) as well as training. There is also a focus on inclusion of women and the most vulnerable, as this is one of the core social missions of the company. The revenue stream of the business-to-farmer model is generated from the farmers' purchases of inputs. Good data on all farmers' daily activities are essential. There are certainly margins for improvement – for example, in the weather forecasts (for farming and warehouse delivery), where efforts are also being made to promote machine learning.

What are the prospects for further scaling up the bundled services in other countries and contexts? There must above all be a clear business perspective. There are currently several barriers at the macro and micro levels (e.g. infrastructures and logistics), and the business model has to be twinned with the local market. In terms of possible transformative actions, the quality of the data (e.g. weather forecasts) should improve. Farmerline is working with research and extension to improve its services, especially those related to advisory.

5.3 Rural Taobao, China

With plans to establish service centres in 100,000 rural villages (one sixth of the total) from 1,000 counties in China in the next three to five years, Alibaba's Rural Taobao can already be considered one of the most successful super-platforms in the world. It was initiated in 2014 as a public service initiative to increase adoption of e-commerce in China's remote rural areas (Khanna et al. 2019). Alibaba initially partnered with local businesses and young returnees to operate village service centres, which served as logistical and educational hubs to help villagers sell their products online. The model then evolved to encompass agro-advisory services (including Alibaba's artificial intelligence and big data engine for agriculture advice, ET brain), supply chain management and last-mile logistics, farm and mechanization inputs, and financial services (payments, agro-insurance, urban-rural crowdfunding and group lending). At the core of the Rural Taobao model is the combination of digital technologies and human networks, especially agents (assistants) operating on the ground around the village centres. There are several business models supporting the system, including business-to-consumer in the case of village centres and consumer-to-consumer in the case of the e-commerce marketplace. The idea behind it is that this portfolio of digital solutions enables rural communities to access a broader variety of low-cost goods and services (i.e. agriculture inputs, health, insurance and typical urban consumer goods), and helps farmers sell their products to urban consumers, while at the same time improving farmers' productivity and encouraging value-added rural enterprises.

There is growing interest from Alibaba in expanding its activities in Africa. The entry of such super-platforms into the region in the medium to long term could revolutionize the way African value chains operate. Alibaba alone is investing 10 times annually in Taobao what the entire private sector is investing in all of Africa's D4Ag enterprises each year (Tsan et al. 2019). This gives an idea of the scale of the efforts required. In the case of expansion to Africa, some of the bottlenecks discussed in the case of Farmerline may well apply. Despite the evident economic leverage of such a big global player, the potential for scaling and self-sustainability depends very much on local factors, ranging from engagement with local partners (actors in the value chain, service providers and, ultimately, the communities that are important for the successful combination of digital solutions, physical infrastructure and human last-mile networks) to the policy and business environment. Super-platforms are also usually proprietary, custom-built digital platforms entirely owning the system and the data behind it, raising issues of inclusiveness and ethics in data-sharing and monetization of private data.

6. Discussion

6.1 Main takeaways from this study

A range of literature and documentation, consisting of both academic and non-academic research, discusses the role of ICTs and digital solutions in agriculture. Several international bodies have taken the lead in tracking ICT adoption trends, and compiling experiences and best practices, in this rapidly growing sector (World Bank Group 2016; Tsan et al. 2019). This body of literature has been mapped on drivers, components and outcomes. From the previous sections of this paper, it is, however, evident that rigorous and quantitative evidence of impact on outcomes is still lacking, even though many technologies have been documented as potential drivers. Also, behavioural drivers of low adoption and disadoption of ICTs remain understudied.

The lack of quantitative and more rigorous evidence is especially applicable to the relatively new use cases such as supply chain management in agriculture, macro-intelligence and integrated solutions (bundles of services and super-platforms). Also, a lot of the evidence focuses on smallholder farmers as the unit of analysis, while less attention is paid to intermediary structures and other stakeholders along the value chain. More in general, it remains unclear to what extent evidence of impact, or its absence, is driven by publication bias and bias against null results. Transparent pre-analysis plans, and registration of evaluations in open access repositories, remain the exceptions, and it is hard to assess whether the published evidence is overpromising as a result. The growing demand for rigorous evaluations should be established early on in project plans, so that piloting and scaling can be designed around this need, and the necessary steps for divulging results are taken irrespective of project success.

Some important conclusions across the use cases can be identified, however. There is an indication of low productivity elasticity of ICT solutions in LMICs (i.e. it is better if such ICT services do not lead to systematically higher crop productivity). This may be a result of several constraints in the enabling environment, including a lack of human capital specifically in terms of digital literacy, and the ability to address the whole farmer ecosystem, which is recognized as another key complementing element for increasing farmers' productivity and wealth. There is evidence, for instance, that solutions that increase input use, market access and opportunities for off-farm income improve financial access altogether. There is also evidence that comprehensive value chain solutions that integrate market linkages with financial payments or logistics achieve greater impacts on profitability.

Another finding is that a large portion of the ICT solutions on offer reveal great potential at the pilot stage but fail to gain traction at the scale-up stage, with generally low adoption rates and short product life cycles. This cannot be attributed entirely to a lack of human capital or a proper enabling environment. Uptake may be hindered, first, by behavioural responses that outweigh potential adoption risks while underwriting future benefits, among other things. Second, one-size-fits-all solutions may be perceived as tailored poorly to individual needs, and smallholders may have a strong preference for traditional and status quo practices regardless of their actual ICT literacy. Third, there are high initial investment costs in terms of learning and familiarization. While evidence of these mechanisms and how to assuage them is still sparse in the rural development context, it is surprisingly attuned with similar findings regarding innovation adoption among small- and medium-sized enterprises in Europe (e.g. Fries et al. 2016; Bigliardi and Galati 2016). The issue of high adoption and learning costs is consistent with a modelled scenario in which smallholders with high internal set-up costs shy away from innovation unless it has a clear and high value added, otherwise opting to forgo the opportunity. This has two implications. First, it limits the magnitude and speed of innovation diffusion among people who clearly stand to benefit from it; and, second, if these costs are fixed to learning a new ICT platform, application or instrument, then integrated solutions offering multiple services on the same interface – and thus a higher value added at once – could help ease the adoption constraints. This is not unlike the practices of, for example, social media outlets that tend to centre a multitude of services, including some that are individually unprofitable, into one integrated platform.

Overall, these conclusions point to three directions for future development: (i) a technical transformation pathway towards increased bundling of solutions serving as much as possible the whole farmer ecosystem; (ii) an urgent need for a human capital agenda and ways to improve digital literacy, hence supporting transformation in the behavioural sphere; and (iii) the need for an analysis of the enabling environment to support the impact potential and inclusivity of digital technologies. In other words, digital solutions supporting market linkages, credit access, supply chains and de-risking (through climate-aware farming, insurance, non-farm income, etc.) should all be coupled with increased digital awareness and skills for farmers, with sufficient local access to specialists who can support the developments with appropriate skills and techniques.

6.2 Systemic challenges impeding value chain transformation

In the reviewed literature, a number of important challenges emerge that are impeding the transformation of value chains through digital solutions and digitalization processes and are not directly incorporated into a food systems approach.

Some of the challenges are related more specifically to digitalization and include poor telecommunications infrastructure and connectivity (namely, for mobile broadband communication), especially in rural areas and especially in Africa. This often leads to unaffordable access to connectivity, let alone to advanced digital solutions for farmers (World Bank Group 2019b). The weak understanding of opportunities brought about by such solutions is also a factor limiting their uptake by many actors. This includes farmers, who in this case also suffer low literacy and a lack of digital skills, a barrier often shared with policymakers and staff in extension systems (Tsan et al. 2019). The Food and Agriculture Organization of the United Nations observed that most countries in the Asia-Pacific region lacked effective digital agriculture strategies that involved multiple stakeholders, and aligned public and private initiatives to deal with issues of connectivity and digital literacy (FAO 2016).

Key systemic environmental and development challenges have a broader and more indirect impact on digitalization effectiveness in transforming food value chains. These pertain to the biophysical, demographic, socio-economic and political spheres, which are often interconnected. Examples include how climate change, land degradation and eventually desertification can deepen poverty traps, limiting the opportunity for smallholders to adopt climate-aware solutions, including digital ones. Digital transformation can be enabled through conducive national policies. However, such policies would generally require an openness of public-private partnerships. A lack thereof may become an impediment to the development of win-win solutions, given the important role of the private sector.

Public health is yet another example. Recently, the COVID-19 pandemic has shown the effect of a potentially positive acceleration towards digitalization. The pandemic could be a catalyst to help close the current gaps, particularly in LMICs, accelerating digital transformation in sectors such as financial services, retail, education, agriculture and government. This could further promote the needed infrastructure investments, including those in backbone networks and last-mile connectivity, as well as electricity supply (McKinsey and Company 2020).

However, this impetus comes with some important caveats. For instance, it has been observed that falling profits in the global insurance market are leading to less investment in the microfinance sector, which is certainly one of the preconditions for more affordable financial products for smallholders in LMICs. In general terms, the concern, supported by some very initial evidence, is that those without access to ICTs are even more disadvantaged than before, and that the lifeline provided by digital technologies is only available to those who can already access them.

It is useful to further consider the financial sustainability of digital services, and their underlying delivery and business models. On sustainability, the importance of profitable business models should be taken into account from the perspective of initiatives supported by public funding, and private sector agro-technology offerings, as well as mixed solutions of public and private investments and ownership.

Tsan et al., (2019) observe that the economics of digital solution providers are improving, including on the African continent, and several players are beginning to develop strong business models, although the vast majority still rely on donor funding. Several commercially successful cases in Asia are described in FARMFIT (2020). The same source indicates that, in recent years, evidence is building on what models do not work, while more understanding is needed about what models do work. For example, the unwillingness and/or inability of farmers to pay for digital agriculture services has been consistently portrayed as a major barrier across the two decades of the presence of digital technology in Africa. There is evidence that farmers are unlikely to pay for digital services (especially advisory services, less so for market linkages where benefits are more immediate), and that it can be challenging to monetize data. Moreover, in some countries this is opposed by governments, which believe that services to farmers, especially smallholders, should be free of charge by virtue of their poverty and vulnerability.

There is a growing trend promoting innovative business-to-business models, together with more traditional business-to-farmer and business-to-government models. Also, the revenue streams of the providers are becoming more diversified, combining digital and non-digital services (e.g. sale of agricultural assets), and opting for usage and subscription fees instead of licensing fees for their products and services (Lohento and Sotannde 2019). Tsan et al. (2019) indicate that while 70 per cent of revenue-generating enterprises in the relevant sector have user payment revenue streams, these do not appear to constitute the majority, as organizations have oriented themselves towards other businesses and players (financial institutions, processors and agribusinesses, market linkages, mobile phone operators, etc.), even if the final service is provided to the farmer. Online advertisement, on the contrary, seems to have a limited scope for now.

Prospects for the future suggest growing addressable markets, where providers will benefit increasingly from “software as a service” solutions, benefiting from associated services creating value addition rather than from selling software or data. D4Ag service providers need to create more value for farmers and other customers across the value chains to attract them, acting as digital intermediaries (Tsan et al. 2019). There is evidence that this works economically for all actors when consolidating fragmented value chains by removing other intermediaries (e.g. digitally linking farmers to retailers for crop sales, bypassing village agents and traders), or reducing value chain “leakage” (e.g. using digitized logistics and market linkages to reduce post-harvest losses). The providers can then further supplement such revenues with streams coming from bundling their services (e.g. financial services fees and, potentially in the future, even revenues from data monetization).

Addressing these challenges offers the opportunity to establish better links between the digital technology driver and the political, economic and social drivers in food systems transformation pathways.

6.3 In search of complementarities

Although there is not yet sufficient empirical evidence on integrated solutions – with their different degrees of product/service integration, approaches and players – they appear to have the potential to unlock a remarkable impact on smallholder farmers, as well as economic attractiveness for actors throughout the value chain. An important distinction between bundled digital solutions, where mostly emerging (often local) D4Ag innovators are taking the lead, and super-platforms is introduced. The latter are currently being promoted mostly by global digital e-commerce players, and potentially in the future by financial institutions, mobile network operators, agribusinesses, market linkage specialists and government- or donor-led public-private partnerships. Super-platforms led by global e-commerce leaders are likely to mobilize the massive investments needed, not only in terms of deploying the digital solutions themselves but also in leveraging other complementary infrastructural investments such as electricity and connectivity grids. They can, therefore, be considered a potentially formidable vehicle for the digital transformation of value chains and food systems. It is not yet clear how to best engender enabling policies to govern the potential inequalities that could arise. Nor is it clear if and how local versions of super-platforms can be promoted, and which policy levers and public investments governments should consider to promote them. An important starting point is to be aware of both the promise and the peril that these actors offer in the domain of ICTs and food systems transformation. This must be followed by active monitoring and multi-stakeholder engagement, rolling assessments and evaluations, and readiness to develop and promote adjustment mechanisms to curtail the potential for market distortions. As usual, the balancing act for policymakers engaging with global e-commerce players is frail, and the risk for dominant positions to become entrenched should not be underestimated.

There are a number of additional concerns raised by the trend of integrating solutions as technology drivers together. A key concern is related to which segments of the rural communities will be served by bundled solutions and super-platforms. It is likely that the most disadvantaged communities and segments will not be the preferred customers. Another concern is related to the prospects of innovative local ICT service providers threatened by the existence of the big global players behind the super-platforms. Ultimately, the contribution of ICTs and digital solutions to (positive) food systems changes will need to be evaluated against the potential of spillovers, negative externalities and net losers. While it is hard to elicit the full extent of these consequences ex ante, it is of utmost importance that policymakers are aware of such threats, especially for those who are underprivileged and disadvantaged to begin with. Such awareness should be the cornerstone of an increased push to monitor and evaluate innovations, as well as to understand interventions that can help mitigate these risks. Only through a cycle of awareness, monitoring and transparent evaluation can rightful policy adjustments take place, and market distortions be minimized. Also, more ex ante assessments of technological innovations are required to make the potential positive and negative impacts explicit.

The proliferation of D4Ag bundled and super-platform solutions – many at national or value chain levels and with multiple successful players and models – is likely to be consolidated over time (Tsan et al. 2019). Given the established presence of information asymmetries and other market failures in different contexts, the risk that a few dominant actors generate monopolistic positions of advantage, thereby raising barriers to entry that curtail rather than promote innovation, should not be overlooked. Policymakers must monitor and promote the interoperability of super-platforms and bundled solutions.

In Kenya, as of mid-2018, the main mobile money operators (Airtel, Safaricom and Telkom Kenya) established a way to allow seamless money transfers across networks, with the auspices and guidance of institutional actors. While this policy is going in the right direction, and is in many ways exemplary, the Kenyan mobile money market remains (as of 2020) largely in the hands of one actor, with a market share of around 99 per cent. This is an indication of how important it is to break quasi-monopolistic positions with active adjustment policies, and of how difficult it is to dilute the market share of entrenched and dominant actors. Similarly, local policymakers and international stakeholders should enable and pursue practices that promote intercommunication and interoperability across ICT innovations, bundled services and platforms, to transform the current myriad of separate digitally enabled propositions into truly paradigm-shifting solutions.

In fact, while the evidence reviewed in this study points to low productivity elasticity of single ICT innovations, an enabling environment in which digital solutions can be integrated and cross-fertilized may lay promising ground for much stronger and more inclusive impacts. The varied policy regimes, value chains and infrastructural and cross-border trade challenges of the global South all indicate that the most likely scenario would be that of an ecosystem in which competing and sometimes collaborating solutions and providers coexist. This implies that enabling environments can differ widely on a national or even regional basis, thus leading to high investment costs for digital solution providers to move from one geography to the next, or from one value chain to another. Also, the deployment of technologies across use cases in such diverse environments is challenging, as technical data and analytical infrastructure will need to be reconfigured and rebuilt every time. The more common it is to have building blocks in place, in terms of data, standards and operating agreements for digital solution providers, the lower their investment costs, and the easier it becomes to increase their scale. Such common building blocks could jointly form a technical infrastructure that acts as a public utility in much the same way as roads, telephone networks and electricity networks. Creating a conducive enabling environment would greatly improve the likelihood of impact of digital technologies on livelihoods.

7. Recommendations

The following recommendations offer a perspective on the best way forward for ICTs to maximize their potential impacts on food system outcomes, with a clear role for public institutions, and with the support of IFAD.

First, an equal playing field must exist for global players and local companies to operate, taking stock of their competitive advantages. Also, this level playing field must extend to the interoperability of ICTs, and digitalization solutions and platforms, to support the creation of bundled solutions that maximize synergies and complementarities. This interoperability includes the adoption of shared definitions of important terms related to technology development and impacts across all actors, to avoid misunderstandings in this rapidly developing field. This paper sets out harmonized frameworks as a starting point based on a food systems approach.

Second, those digital solution providers serving the most disadvantaged geographies, communities and segments (e.g. actively aiming to bridge the gender digital divide) will need support. This needs to be combined with the rigorous, transparent and reproducible evaluation of impact of ICT solutions, and the study of behavioural underpinnings of (non-)adoption by (especially) disadvantaged categories, to better understand their interaction and experience with a given technology.

Third, governments must be ready to play a more active role as custodians of national data infrastructure of public utility (such as weather forecasts or comprehensive farmer registration and geolocation, providing strategic datasets that would enable many advanced digital services). Globally, it must be investigated what would be the best public utility function in developing enabling environments with respect to technical data infrastructure, and encouraging synergies of these forms of partnerships as well as non-proprietary interpolations across platforms and ICT solutions, which are likely to be different across geographies.

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Annex 1: Current trends in ICTs and digitalization for agriculture

Information and communication technologies (ICTs) and the internet have proliferated rapidly around the world, with the number of users increasing by about 10 per cent per annum over the past decade (ITU 2019). In developing countries, ICTs have spread faster than other tools for social development such as education, health and infrastructure. While landlines remain the exception (especially in Africa, with penetration of around 3 per cent, by far the lowest in the world), mobile networks have spread very rapidly (ibid.). Although mobile penetration and network connectivity are high in all countries, the adoption of the internet and sophisticated technology has lagged in developing and least developed countries. As of 2016, around 70 per cent of the world's poor people had access to a mobile phone, but only 15 per cent could access broadband internet (World Bank Group 2016). There is, moreover, a clear urban-rural divide in the use of mobile internet connections. GSMA (2019) indicates that rural populations in low- and middle-income countries (LMICs) are 40 per cent less likely than people in urban areas to use mobile internet. From the same source, it can be observed that there is a persistent gender gap, with women 23 per cent less likely than men to use mobile internet. The rural-urban divide and the gender gap are greatest in South Asia and sub-Saharan Africa.

Trends in internet connectivity are promising, with mobile phones being, at least for now, the most important delivery channel. In the 18 LMICs surveyed by GSMA (2020), 57 per cent of those who had used the internet in the previous three months accessed it exclusively on a mobile phone. It is foreseen that by 2030 nearly 80 per cent of farmers will have access to a mobile phone and reasonable fourth generation (4G) connectivity. Many will also have access to smartphones: already more than 25 per cent of smallholder farmers in countries such as Kenya and Senegal have access to them, and numbers are projected to grow quickly (Tsan et al. 2019). In sub-Saharan Africa a subscriber penetration of 50 per cent is foreseen by 2025 (GSMA 2020). 4G will soon become the dominant mobile technology, surpassing half of global mobile connections in 2019, while 5G networks are in the planning stages.

However, by 2025, sub-Saharan Africa will still be lagging behind, with a predicted technology mix of 12 per cent of connections as 2G, 58 per cent as 3G and only 30 per cent as 4G and 5G combined (the latter 3 per cent only). In comparison, 4G and 5G are projected to account for 79 per cent of connections in the Asia-Pacific region, 74 per cent in South America and 54 per cent in the Middle East and North Africa (ibid.). Coverage, moreover, does not necessarily imply use, which can be hampered by unaffordable costs and a lack of literacy and digital skills. The use of the internet and mobile phones does not necessarily imply the use of digital agricultural solutions and services by farmers, as they might use these technologies for social media, communication with families and other reasons.

Technology, however, constitutes a precondition; therefore, in sub-Saharan Africa, more sophisticated applications based on 4G and 5G wireless connectivity (e.g. smart sensors for water and soil fertility management, geographic information system satellites for precision agriculture, e-learning for extension, e-diagnostics for pest management, smart supply chains, etc.) will most likely be able to scale up only over the longer term. Mobile phones with basic features can barely support such advanced solutions, and they are likely to remain the main delivery mechanisms for some years to come in many of the most disadvantaged geographies and rural communities. Migration from 4G to 5G presents a number of challenges that are complex and require time and resources beyond current capacities, especially in Africa. The future is likely to entail management of existing 2G, 3G and 4G investments in preparation for later 5G growth. In terms of the investments needed, the World Bank Group (2019b) estimates that in Africa alone, by 2030 around US$100 billion will be needed to achieve universal access to broadband connectivity. Complementary infrastructure investments, especially in the electricity grid, will also be required to support the needs of advanced connectivity (Blimpo et al. 2019). This reality of rural connectivity and supporting infrastructure indicates that the transition will be slow, and that developing communities will continue to rely on traditional means of communication delivery and telecommunications infrastructure (the limited network of landline telephone connections, radio, emails, basic phones) for several more years.

The implication is that multiple delivery channels and platforms will have to coexist, and that not all advanced applications will be immediately available to all farmers everywhere. Strategies that combine traditional and advanced delivery channels and intermediaries on the ground (extension services, loan officers, street-level agents, etc.) with mobile-based solutions will still be needed in view of the penetration of broadband connectivity and related services.

The Digitalisation of African Agriculture Report 2018-2019 (Tsan et al. 2019) provides a comprehensive overview of the ICT sector's reach and growth, as well as the actual use of the solutions deployed so far, although its focus is limited to Africa. As of 2019, there were at least 390 distinct, active digital solutions across the continent, with over 33 million registered smallholder farmers and pastoralists out of a total of 250 million (ibid.). The most important solutions provided in terms of outreach relate to advisory services, market linkages and financial access. Furthermore, the amount and scale of solution-bundling is increasing, with over half of the solutions combining more than one use case. There is also geographic concentration in use, with two thirds of registered farmers across all solutions based in East Africa, mostly in Kenya. Use, however, remains generally low. Despite challenges in estimating this precisely, it is estimated that only 42 per cent of those registered actually use the solutions, regardless of frequency.

Annex 2: Additional reports reviewed

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Annex 3: Evidence review

Use case 1
Advisory and information services

Type of evidence	*Digital solutions*	*Pathway, outcome or impact*	*References*
Positive evidence	Dissemination of information on best practices	Knowledge learning and capacity Adoption of agronomic best practices Productivity	Fu and Akter (2016) Mittal (2016)
	Participatory learning platforms	Adoption of agronomic best practices Productivity	Gandhi et al. (2009); Cole and Fernando (2018) Larochelle et al. (2019); Van Campenhout et al. (2017)
	Forecasting and early warning systems	Reduction in losses	Fafchamps and Minten (2012); Camacho and Conover (2011)
Weak/no evidence	Dissemination of information on best practices	Adoption of agronomic best practices Productivity	Fafchamps and Minten (2012)
	Forecasting and early warning systems	Adoption of agronomic best practices Productivity	Fafchamps and Minten (2012); Camacho and Conover (2011)
	Diagnosis of soil/livestock/plant health		
	Dissemination of information on conservation practices		
	Precision advisory		
	Planning platforms and monitoring		
	Budgeting and financial management		
	Farmer cooperatives and organization management		

Use case 2
Financial services

Type of evidence	*Digital solutions*	*Pathway, outcome or impact*	*References*
Positive evidence	Money transfer	Reduced transaction costs; improved diversification and value addition Greater agricultural investments	Jack and Suri (2011) Baumüller (2018); Batista and Vicente (2020)
Weak/no evidence	Fundraising platforms		
	Micro-banking		
	Crop insurance		

Use case 3
Market links

Type of evidence	*Digital solutions*	*Pathway, outcome or impact*	*References*
Positive evidence	Off-take market and price information systems	Improved prices and market access Improved planning	Goyal (2010); Nakasone (2013); Courtois and Subervie (2014); Baumüller (2018)
Weak/no evidence	Off-take market and price information systems	Improved prices and market access Profitability	Fafchamps and Minten (2012); Camacho and Conover (2011); Mitra et al. (2018)
	Input supply information systems		
	Input marketplaces		
	Shared machinery services		
	Linkage to buyers and agri businesses		Casaburi and Kremer (2019)
	Off-take marketplaces and commodity trading		

Use case 4
Supply chain management

Type of evidence	*Digital solutions*	*Pathway, outcome or impact*	*References*
Positive evidence	Quality assurance, compliance and tracing	Improved prices and market access	Karippacheril et al. (2011)
	Transactions and payments	Improved prices and market access	Sekabira and Qaim (2016)
Weak/no evidence	Access to transportation and storage		
	Quality assurance, compliance and tracing		

Use case 5
Macro agricultural intelligence

Type of evidence	*Digital solutions*	*Pathway, outcome or impact*	*References*
Weak/no evidence	Weather and climate observatories		
	Public sector programme monitoring and evaluation		
	Extension system management		

Use case 6
Integrated use cases

Type of evidence	*Digital solutions*	*Pathway, outcome or impact*	*References*
Weak/no evidence	End-to-end value chain integration		
	Advisories with input linkages		
	Credit assessment with farm advisory		
	Super-platforms		

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