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Digital tools and agricultural market transformation in Africa: Why are they not at scale yet, and what will it take to get there?☆

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ABSTRACT

Despite enthusiasm for the potential of digital innovations to transform agricultural markets in Africa, progress made thus far has been limited to small-scale experiments that often fail to scale up. Realizing the full potential of digital innovations – tools, technologies, applications, and services – in Africa requires not just further development of these solutions at meaningful scales, but also more nuanced evidence from both successful and unsuccessful scaling efforts. This paper reviews the conceptual and empirical evidence on the transformative potential of digital innovations for African agricultural markets with an in-depth examination of solutions that have been rolled out to date in the continent. Specifically, the review addresses the following questions: (i) how can digital innovations improve the functioning of agricultural markets in Africa? (ii) what explains the apparent disconnect of most pilots to scale-ups? (iii) what is required to realize their full potential? and (iv) what are the emerging risks and opportunities associated with digital innovations for agricultural marketing? Although our review of the landscape and literature on market-focused digital innovations in Africa identifies several reasons to remain optimistic, the prevailing disconnect between pilots and scale-ups merits further evaluation. In particular, there is a need for more systematic assessments of both successes and failures at both the piloting and scaling stages.

1. Introduction

The potential of digital tools to transform agricultural markets in developing countries has attracted substantial enthusiasm in public discourse, development policy, and private enterprise and investment circles. Increasing mobile phone and internet penetration in the developing world represents an undeniably fertile landscape for the deployment of information and communication technologies (ICTs). ICTs – ranging from text message and interactive voice response (IVR) systems to mobile apps, satellite imaging, and remote sensing – have the capacity to be customized to varying contexts to deliver services and information in a low-cost, large-scale, and timely manner. Among their many contributions, ICTs can transform agricultural markets, including their structure, organization, and functions, with significant potential to address some of the persistent market failures and information asymmetries that often characterize agricultural markets in developing countries (e.g., Jensen, 2007; Aker, 2010; Goyal, 2010; Courtois and Subervie, 2014; Nakasone et al., 2014; Aker and Fafchamps, 2015; Aker et al., 2016; World Bank, 2016).

This potential has motivated a large number of public and private

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sector initiatives aimed at building digital tools, platforms, and architectures to radically transform agricultural markets. Much of this effort and experimentation has focused on Africa,[1] where markets are comparatively underdeveloped, and where agricultural production is carried out primarily by smallholder farmers operating small, fragmented farms that are often distant from urban areas (Aker et al., 2016). These initiatives have led to a proliferation of digital innovations that address different and often critical pieces of the puzzle: matching buyers and sellers, supplying price information, and reducing the costs and risks of exchanges in goods and services. More formally, these innovations aim to address multiple forms and sources of both market and institutional failures that are common in agricultural markets (Dorward et al., 2004), particularly the persistence of information asymmetries between farmers and traders relating to price discovery, product quality, and transactions costs in formal and informal contracting mechanisms (Jensen 2007; Aker, 2010; Goyal, 2010; Courtois and Subervie, 2014; Aker et al., 2016).

Yet systematic evidence of the favorable impact of these digital innovations remains scarce, and the few pieces of evidence available in the literature are mostly based on relatively small pilot projects. This same body of evidence provides little insight on digital innovations that can demonstrate success at scale in terms of developing or integrating markets, reducing transaction and transportation costs, improving coordination or consolidation of long and fragmented value chains, reducing production and market risk of both idiosyncratic and covariate natures, or remedying the unequal distribution of market power among agents (e.g., Goyal, 2010; Courtois and Subervie, 2014; Aker et al., 2016; Benami and Carter, 2021). Despite ambitious claims of speed, reach, and depth, purveyors of ICT tools have thus far posted only a few large-scale successes that have substantially transformed agricultural markets in Africa. In fact, only a small number of digital tools facilitating financial transactions have scaled to an impressive level in some countries, e.g., M-Pesa and M-Shwari in Kenya. However, even these tools are still not widely used by smallholder farmers and agricultural households. Parlasca et al. (2022) point out that only about 1% of Kenyan farmers use mobile financial services to obtain agricultural loans, and 15% use them for agriculture-related payments.

It may simply be too early in the "digital revolution" to expect impacts at scale. While the growth of mobile phone connectivity has been explosive, Africa still lags behind other regions on ICT, and mobile internet connectivity rates vary greatly within the region (ITU, 2020; GSMA, 2021a; Mehrabi et al., 2021). But it may also be that too little attention is being given to the complex nature of agricultural markets in Africa – markets that involve multiple layers of formal and informal exchanges, intransigent structures and agents, and gaps in digital literacy and connectivity that together create unique and sometimes unsurmountable challenges to transformative, market-driven structural change.

Addressing smallholders' market constraints adequately may require end-to-end digital solutions rather than piecemeal informational apps in an environment characterized by geographic isolation and risky transactions. Unlike the delivery of extension information or agronomic advisory services, the provision of marketing support typically requires whole-of-value-chain coordination: identifying multiple suppliers and consumers of products and services along a value chain, coordinating post-harvest, transport, processing, and warehousing activities, and facilitating services such as price information, credit provision, and payments. Few ICT-based tools targeting agricultural markets are able to fully address multiple constraints on a single platform. For example, those tools that only deliver a specific service (e.g., information) without facilitating transactions (e.g., payment systems) may simply fall short of the mark and hence may not appeal to farmers.[2]

Furthermore, although the proliferation of new technology companies in many African countries is encouraging, the adoption of their products and services seems more limited than many realize. Precise numbers are difficult to come by, but beyond the hype, there are few reliable data sources on use and use-intensity, among other metrics. Moreover, efforts to promote the adoption of digital marketing tools have often required generous subsidies and incentives from governments and donors, with only a few tools (e.g., DigiFarm, iCow, M-Pesa) standing on their own as commercially viable products. Indeed, most digital tools targeting smallholder farmers in African countries remain in the pilot stages, with unknown potential for successful scaling (World Bank, 2016; Baumüller, 2018; Fabregas et al., 2019a, 2019b). This failure to achieve scale is not unique to agricultural markets in Africa: the World Bank (2016) argues that, globally, four out of five startup online commerce platforms are likely to not scale up.

The objective of this paper is to identify encouraging developments and success stories that can inform us about the potential of digital innovations to transform agricultural markets in Africa. Specifically, this review aims to address the following questions: (i) how can digital tools improve the functioning of agricultural markets in Africa? (ii) what explains the apparent failure of most pilots to scale up? (iii) what does it take to realize the potential of digital solutions in African agricultural markets? (iv) what are the emerging risks and opportunities associated with the advent of new digital tools for agricultural marketing?

2. Terminology, methods, and data

To answer these questions, we begin with a key definition to bound the study. We define digital innovation in agricultural markets as mechanisms that rely primarily on ICTs to reduce information asymmetries and transaction costs incurred in the exchange of goods and services in (often imperfect) markets for agricultural inputs, finance, services, and products. The definition covers a variety of mechanisms, for example, digital tools and applications that match buyers and sellers where exchanges are otherwise costly or difficult to arrange, ensure full and equal access to information, build mutual trust between agents, encourage repeated transactions and durable relationships, overcome contract enforcement problems, accommodate market-and context-specific factors and, ultimately, contribute to reductions in the uncertainty, risk, and the costs of monitoring and enforcing transactions in imperfect markets.

Next, we need to contextualize the review methods employed in this study. The study specifically reviews the conceptual and empirical evidence on digital tools for agricultural market transformation in Africa. Although our study is neither a systematic review nor a meta-analysis and hence may fail to provide an exhaustive review of a rapidly expanding literature, we choose this traditional review format because it provides an opportunity to introduce novel concepts, synthesize different strands of literature, and identify knowledge gaps in a manner that other approaches may not.

The review process was carried out as follows. We began with a search on Google Scholar for "digital tools for agricultural marketing in Africa" written within the last 10 years and sorted by relevance (as determined by Google Scholar). We then selected the first 100 articles for initial review, based on a subjective assessment of whether they met the criteria of whether they were bona fide scholarly publications (journal articles, working papers, books, book chapters, or research reports), and whether they provided sufficient conceptual and/or empirical evaluation of the functional roles, adoption and/or impacts of

[1] In this review, the term "Africa" refers to the economies that are geographically situated within all of the African continent, not only those that are referred to as economies or countries located "south of the Sahara."

[2] Some recent digital platforms (e.g., CropIn, Kuza, Lersha) do bundle extension advisories with marketing tools (although not payment platforms per se), but it is too early to see how well these platforms are scaling relative to more focused tools.

digital decision support tools for agricultural marketing in sub-Saharan Africa. Next, we conducted a series of discussions with experts who have conducted research on digital decision support tools in the context of smallholder agriculture in Africa, and who work in member centers of CGIAR to solicit recommendations for relevant papers. The resulting set of papers was reviewed by the authors, with the set of papers cited in the article being the result of consensus about the rigor and relevance of each.

Finally, we need to explain how our inventory of market-oriented digital innovations was developed. Our first step was to compile an inventory of market-oriented digital innovations along with a characterization of their attributes and highlight how these digital tools may transform agricultural markets in Africa from the available literature, from web services, and from expert insights collected during the review process described above. This was followed by an effort to typologize the elements in our inventory, as detailed in the next section. This process allowed us to both compare and contrast performance across digital innovations, and to further explore the record of success and failure as well as the disconnect between piloting and scaling. We use this as the basis to discuss how African countries can harness digital solutions and to reflect on encouraging trends and emerging risks.

It is worth noting that this is not the first review on the potential of ICTs in agriculture. Several other papers evaluate the contribution of digital tools to transforming agriculture, albeit with different foci and coverage. Aker and Mbiti (2010) and Aker et al. (2016) provide a comprehensive review of the earlier literature on the potential of ICTs to provide various types of agricultural extension and related services. Fabregas et al. (2019a) and Spielman et al. (2021) review recent literature on the effectiveness of ICTs to deliver agricultural extension and advisory services in developing countries, while Benami and Carter (2021) synthesize the potential of digital technologies to reshape rural microfinance. Nakasone et al. (2014) and Nakasone and Torero (2016) discuss the potential of ICTs to support agricultural development, including through market information systems, for which they find a paucity of empirical evidence, weak impact on prices among available studies, and the possibility for considerable heterogeneity in impacts across value chains and actors.

It is also worth noting that this is not the first inventory of digital innovations in developing-country agriculture. CTA (2019) provides what we believe to be the most extensive inventory of agriculture-focused digital technologies in Africa, identifying 390 unique technologies in Africa. Our review is closely related to CTA's seminal landscaping exercise given that theirs is a valuable first step in improving our understanding of the rapidly growing collection of digital tools in agriculture. However, our paper differs from the CTA landscaping and the reviews cited above in several ways. First, we provide a higher-resolution (and hence more focused) analysis of digital innovations that specifically address market-related issues. We analyze these innovations within a typology of market-related services, covering four distinct categories: (a) market advisory and information services; (b) agricultural e-marketing tools that facilitate market linkages; (c) e-financial services that facilitate a range of financial transactions; and (d) tools that collect agricultural market data using crowdsourcing services. We draw on a substantive list of digital tools in agriculture to populate our typology and examine each type-class more systematically. This typology distinguishes different forms of digital innovations that are often lumped together in discussions despite important functional differences.

Second, our review covers more recent innovations and evaluations that emerged during the last decade, keeping pace with the rapidly evolving ICT sector that quickly renders reviews obsolete.[3] In that sense, our paper responds to emerging trends and knowledge gaps, including those related to explaining the apparent disconnect between pilots and scale-ups observed in the last decade. Finally, our review limits itself to digital innovations aimed specifically at improving agricultural markets, and we evaluate the quality of evidence with respect to impact and scale. Although these markets share many commonalities with markets in other developing regions, they are also beset by what are arguably several rather unique attributes – most notably, the considerable market fragmentation, limited spatial integration, and infrastructural constraints, all of which digital innovations seek to address – that warrant this focused attention.

3. Typology of digital tools supporting agricultural markets in Africa

Our analysis indicates that the types of digital innovations aimed at supporting agricultural markets in Africa have evolved considerably in recent years. Early on, digital solutions emerged with a focus on the provision of market information via analog channels such as radio, television, and other media. An example of the latter was the network of price "tickers" set up in the mid-2000s by the Ethiopian Commodity Exchange (ECX) in district markets/headquarters across Ethiopia to provide farmers and traders with equal access to real-time price information. Since then, digital innovations focused on agricultural markets have expanded and diversified across multiple dimensions in Africa. We examine four classes of these innovations below, with a summary provided in Table 1 and further details in Table A1 in the Appendix.

The first class typically delivers market price information and advisories with the purpose of overcoming information asymmetries between farmers and traders, thereby improving price discovery and the distribution of gains from trade between parties. Several notable market information systems launched in the early 2000s typify this class (Tollens, 2006). These include non-excludable public services that make relatively high-frequency price information on selected commodities widely available to farmers, traders, and other commercial actors in rural areas. Examples include the Sector Information System (SIF) in Cameroon, the Agricultural Market Information Center (AMIC) in Zambia, the Livestock Market Information System (LMIS) in Kenya, and the ECX in Ethiopia, among others. This was followed by the emergence of more excludable, fee- or membership-based private digital services run by commercial entities or farmers themselves, such as the Agricultural Commodity Exchange Ltd. (KACE) in Kenya, Esoko in Ghana, El-Mofeed in Egypt, and Infotrade in Uganda. These digital innovations still appear to be the most dominant type in Africa, both in terms of use and coverage (CTA, 2019).

The second class of digital innovation consists of platforms that link farmers to products and services, often with the aim of reducing marketing or transaction costs incurred by farmers or traders. Many such platforms have emerged in recent years and are rapidly evolving in terms of scale and commercial viability. There is considerable heterogeneity among these platforms, ranging from services for seed, fertilizer, and pesticide supply (e.g., Kobiri in Guinea, Lersha in Ethiopia) to custom-hired mechanization services (e.g., Hello Tractor in Nigeria, TroTro Tractor in Ghana) to wholesaling and retailing services (e.g., Farmster in Tanzania, Freshfarm in Egypt, Hmizate in Morocco, Agro Market Day in Uganda) to matching farmers and other agents with transport providers (e.g., Transzam in Zambia connects truck drivers and farmers, SafeBoda in Uganda connects motorcycle drivers and customers) to time-sensitive market facilitation between sellers and

[3] The CTA (2019) landscaping exercise itself notes that, at the time of its publication, there were at least 390 distinct, active digital solutions focusing on agriculture, with two-thirds of them having been launched during the three years preceding their survey.

Table 1
Typology of market-oriented digital innovations in African countries.

Type/class of innovation	Description	Functions	Examples (Country)
Market advisory and information services	Digitally enabled tools to deliver market information and advisories as a means of addressing different forms of market and institutional failures, particularly asymmetric information and high transactions costs	• Supply commodity and input price intelligence Provide customized or precision market advisory services Facilitate peer-to-peer market information-sharing platforms	• 80–28 Farmer Hotline (Ethiopia) iCow (Kenya) N'Kayo (Kenya) Ethiopia Commodity Exchange (Ethiopia) Farmerline's 399 Service (Ghana) Verdant Agritech (Nigeria) Mzar3ty (Egypt) Mahsoly (Egypt)
Market linkages	Digital information-sharing tools to link farmers to suppliers of relevant farm inputs such as seeds or fertilizers; suppliers of production and machinery services such as tractors; or even to wholesalers/ retailers	• Link supply and demand for inputs, technology, mechanization, and other services Link supply and demand among supply chain actors	• Hello Tractor (Nigeria) SunCulture (Kenya) iProcure (Kenya) Kobiri (Guinea) Lima Links (Zambia) Agro Market Day (Uganda) Freshsource (Egypt) Tekeya (Egypt) Hmizate (Morocco) NINAYO (Tanzania)
Agricultural financial services and transactions	Digital services that facilitate market transactions and financial services, aimed at lowering transactions costs and risks, or at improving efficiency and accountability in market exchanges, or improving quality assurance and traceability of agricultural products	• Supply e-wallets and payment solutions Provide lending and saving services Manage product traceability systems Provie quality assurance and certification Supply insurance and credit solutions Support enterprise resource planning	• Akellobanker (Uganda) M-Pesa (Kenya) Bayseddo (Senegal) SmartMoney (Tanzania) AgroPay (Ghana) AgriMisr (Egypt) Enda Tamweel (Tunisia) Ari.farm (Somalia)
Agricultural market data collection, crowdsourcing services, and big data	Digital tools that can collect market data from farmers while also allowing interactions between farmers. These tools, although at early stage, create unique opportunities to collect rich data in a timely manner	• Provide business-to-business analytical services Crowdsource data on pricing, agent performance, or other services Provide market advisory services that integrate satellite-based remote-sensing and other data streams with machine learning and artificial intelligence	• KAZNET (Kenya) DigitalGreen (Multiple) Farm.ink (Multiple) N-frnds (Multiple) Nuru (Kenya) Attaisir (Morocco)

Source: Authors' compilation.

buyers of highly perishable goods (e.g., AsmakNet in Egypt, which connects fish farms directly to buyers).[4] Although many of these platforms rely on commission-based revenue models, others have evolved without clear revenue-generating strategies, raising important questions about their long-term commercial viability.

The third class of digital innovation is services that facilitate financial transactions between value chain actors, e.g., between farmers and traders, or between aggregators and processors. Many of these innovations aim to reduce the time, cost, and risk associated with exchanges in imperfect or incomplete markets. Examples include financial transaction platforms such as M-Pesa in Kenya, AgriMisr in Egypt, and AgroPay in Ghana, or platforms that also provide loans such as Enda Tamweel in Tunisia and Musoni in Kenya. Some digital innovations in this class also bundle or integrate their services with other functions such as market information provision, farmer-to-market platforms, or extension and advisory services. This includes platforms such as Farmcrowdy in Nigeria, SmartMoney in Tanzania, and Twiga Foods in Kenya, which connects smallholder farmers to urban vendors through a mobile-based platform that guarantees higher prices to farmers while also making use of M-Pesa to monitor and track transactions. M-Pesa is possibly the most well-known success story in this class, as a result of its money transfer services and as well as smooth integration into other services. But, as Parlasca et al. (2022) point out, financial services like M-Pesa remain under-utilized by smallholders and cannot yet be linked to transformative changes in agriculture.

The fourth class of digital innovation covers those that collect agricultural market data based on crowdsourcing, remote data collection methods, machine learning, and artificial intelligence. While this class of tools is still at an early stage and offers limited functionality, there is considerable interest in their potential to revolutionize the availability and use of market data. Some tools in this class use open-source software and crowdsourcing to manage the costs of collecting and analyzing high-frequency data on commodity prices, quantities, shipments, and other data points that are useful to a range of market actors (see, e.g., Alulu et al., 2020; Steinke et al., 2021). Other tools harness satellite-based remote-sensing to collect and analyze information from both large-scale production areas—key breadbaskets across Africa—as well as remote and otherwise inaccessible areas where market opportunities may be underexploited. They can complement conventional market data collection methods and have received substantial traction in fragile and remote areas (Hoogeveen and Pape, 2020). Examples include KAZNET, which crowdsources livestock market information from pastoralists in Kenya (e.g., ILRI, 2017; Alulu et al., 2020); and Orange Garbal in Mali, which collects data and information on grazing quality and availability (CTA, 2019). Interestingly, most of these tools are designed first and foremost for data extraction, with few providing feedback loops that return information to the data providers—farmers, pastoralists, and traders. The next logical step would be to use crowdsourced data and other types of "big data" to inform decision-making by value chain

[4] See CTA (2019) and Malabo Montpellier Panel (2019) for additional examples and details.

actors, for example, by farmers for rating input providers on the quality of their products and services. An example of this was piloted in Uganda with agro-input suppliers selling maize seed in a market plagued with quality and trust issues (Miehe et al., 2023), building off a similar approach in Pakistan with artificial insemination services for livestock (Hasanain et al., 2018).

So far, several of these digital innovations have recorded significant success stories that are worth mentioning. For instance, M-Pesa has been shown to be associated with increases in consumption and household incomes (Suri and Jack, 2016; Kikulwe et al., 2014). These digital financial services have also been critical in protecting and cushioning households from income and health shocks through increased remittances (Jack and Suri, 2014). These impacts have been shown to be more pronounced for women and female-headed households (Suri and Jack, 2016). These digital innovations have particularly been relevant for farmers in the horticultural value chains such as those cultivating fresh fruits like bananas (Hartmann et al., 2021; Kikulwe et al., 2014). Relatedly, success stories also emerge from livestock-geared digital innovations such as iCow and KAZNET which have been shown to be relevant for livestock farmers and overall livestock development in semi-arid and arid regions (Daum et al., 2022; Chelanga et al. 2022). Other tools like M-Kilimo in Tanzania and Kenya as well as WeFarm in Kenya and Uganda have a great reach and have been effectively scaled up with large implications on smallholders.

4. How can digital innovation transform agricultural markets in Africa?

As noted earlier, a relatively large literature has examined the potential of digital innovation to transform the functioning, efficiency, and equity of agricultural markets by addressing critical market and institutional failures. Yet even with a rich theoretical and empirical body of work – summarized in Table 2 and classified according to the typology set forth in the previous section – it is still useful to explore the multiple pathways through which digital innovation affects agricultural markets, particularly in the unique African context. To that end, this section reviews the economic theories, conceptual frameworks and empirical evidence that underpin this study.

First and foremost, prior studies examine digital innovation in terms of their capacity to transform agricultural markets via improvements in *(1) input and output market efficiency, and (2) spatial and temporal market integration.* The majority of these platforms target various forms of market failures by providing farmers and other upstream agents with market information on prices, quality requirements, and market outlets to make bargaining positions more equitable and markets more competitive (Table 2). Multiple studies document how tools overcome information asymmetry to reduce search costs, reduce price dispersions, and ultimately improve agricultural market efficiency. For example, Aker (2010) and Aker and Fafchamps (2015) show that the expansion of mobile phones reduce price dispersion in agricultural markets in Africa.[5] Belay and Ayalew (2020), Andersson et al. (2017), and Hernandez et al. (2017) show that localized price information provided by the ECX in Ethiopia reduces price dispersion and hence improve market integration. Courtois and Subervie (2014) show that a mobile-based market information system (Esoko) in Ghana leads to a 10 percent increase in farmers' selling prices.

Prior studies also explore how digital solutions can improve agricultural market performance and efficiency by *matching supply and demand.* These tools can improve input-use efficiency by coordinating transactions, thereby improving farmers' timely access to required inputs and services. For instance, several digital solutions aim to provide time-critical services that increase access to agricultural inputs, machinery and farm services (World Bank, 2012; Okello et al., 2020). Others create markets where none existed, for example, matching machinery rental and custom-hiring services with smallholders who would otherwise be difficult to reach through brick-and-mortar retailing (e.g., Daum et al., 2021).

Prior studies further examine digital innovation as a means of *improving the accountability, transparency, and traceability of market transactions.* Typical agricultural market transactions in African agriculture are conducted as cash exchanges in spot markets or through relational contracts (e.g., Macchiavello and Morjaria, 2021), exposing agents to a wide range of risks and transactions costs. Some digital tools can reduce monitoring costs and enable greater accountability between agents by facilitating transparency, traceability and, when necessary, opportunities to pursue recourse when a transaction fails (e.g., Grossman and Tarazi, 2014; World Bank, 2016; Fabregas et al., 2019b; Aker and Cariolle, 2020; Banerjee et al., 2020). Other tools can also supply essential financial services and facilitate otherwise difficult or costly transactions, as exemplified by mobile money applications such as M-Pesa in Kenya (e.g., Suri and Jack, 2016; Suri et al., 2021). Still other tools can assist in ensuring the quality and traceability requirements for exports to Europe, as demonstrated among farmers in Botswana seeking access to European markets (World Bank, 2016).

Furthermore, earlier studies also indicate that digital innovations may improve *value chain aggregation and formalization,* where fragmentation across a given value chain is a constraint to coordination and delivery of marketing services (CTA, 2019; Malabo Montpellier Panel, 2019). Some tools, particularly e-market platforms, can improve market coordination and efficiency by shortening supply chains in a manner that circumvents commission agents and other "middlemen", instead linking producers directly to consumers, especially in high-value markets, and allowing for each to enjoy a greater share of the value created in the chain (Sekabira and Qaim, 2017). For example, Iacovone and McKenzie (2019) show that digital support tools shortened the supply chain for fruits and vegetables in Colombia by reducing the amount of time and cost for purchasing products, with important impact on venders' work-life balance and end prices for consumers.

Other studies also suggest that digital innovation can facilitate the efficient use of farm inputs and services, and hence *improve returns to farming and the participation of smallholders in markets* (World Bank, 2012; Okello et al., 2020). For example, digital tools can be designed to integrate traditional agronomic advisory services with digitalized information such as soil quality and weather patterns, and then deliver a customized or site-specific basis at the farm or plot level and on a seasonal or intra-seasonal basis. These same digital tools can also integrate farm budgeting and bookkeeping, farm management, seasonal planning, farm operations monitoring, and, in the case of larger farms, more complex supply chain management functions. That said, many of these integrated tools that operate on both the production management and commodity marketing sides of the equation are still at a nascent stage of adaptation for smallholders (CTA, 2019; Birner et al, 2021).

Next, some studies examine digital innovation as a mechanism *to improve the resilience of agricultural markets and to protect market actors from unanticipated shocks*. For example, digital tools can potentially facilitate marketing transactions in conflict-affected regions and other contexts where in-person exchanges may not be feasible, although strong correlations between conflict and digital infrastructure may limit the potential of this pathway, as Tkach and Williams (2018) discuss in the context of Democratic Republic of the Congo. More relevant may be the use of digital tools to manage idiosyncratic shocks. For example, Suri et al. (2021) show how M-Shwari, a digital tool that facilitates digital loans, improved households' resilience to shocks in Kenya. But even in the presence of broader co-variate shocks, there is suggestive evidence

[5] Other studies show similar evidence from other Asian countries (e.g., Goyal, 2010). However other studies from Africa (e.g., Molony, 2008; Burrell and Oreglia, 2015) and Asia (Fafchamps and Minten, 2012; Mitra et al., 2018) find no significant and major effects of mobile phones and associated services. These mixed findings may suggest that the impact of these services may vary across contexts.

Table 2
Impact of digital tools on agricultural markets: A summary of empirical evidence.

Type/class of innovation	Author(s)	Country or region	Digital tools/platform	Main findings
Market advisory and information services	Aker, 2010; Aker and Fafchamps, 2015	Niger	Mobile phone service; Mobile phone coverage	Reduced price dispersions; Reduced spatial producer price dispersion for semi-perishable commodities
	Courtois and Subervie, 2014	Ghana	Mobile-based MIS	Increased price received by farmers
	Svensson and Yanagizawa, 2009; Muto and Yamano, 2009	Uganda	Radio-based MIS; Mobile phone coverage	Increased farm-gate prices; Increased market participation of farmers in remote areas who produce perishables
	Futch and McIntosh, 2009	Rwanda	Grameen/MTN Village Phone	No effect on prices, business profits, and consumption
	Belay and Ayalew, 2020; Tadesse and Bahiigwa, 2015	Ethiopia	ECX price tickers; Mobile phone ownership	Increases the average farm-gate prices for traded commodities; Increase amount of marketed surplus, but limited effect on prices received by farmers
	Chikuni and Kilima, 2019	Malawi	Mobile-based MIS	No effect on farmers market participation
	Kikulwe et al., 2014	Kenya	Mobile money	Reduced liquidity constraints and promote agricultural commercialization
Market linkages	Daum et al., 2021	Nigeria (and India)	Digital tool for tractor hire	Reduced transaction costs for service providers
	Katengeza et al., 2011; Katengeza et al., 2013	Malawi	ICT-based MIS	Reduced spatial price dispersion; Strengthen farmers market linkage, reduced transaction costs and increased agricultural incomes
	World Bank, 2012; Okello et al., 2020	Kenya	Mobile applications; ICT-based market information projects	Increased farmers income and improved supply chain efficiency (through market integration and reduction of transaction costs); Increase farmers participation in input and output markets, and their household income
	Sekabira and Qaim, 2017	Uganda	Mobile money	Mobile money users sell a large share of their produce to buyers in high-value markets
Agricultural financial services and transactions	Suri and Jack, 2016; Suri et al., 2021	Kenya	M-PESA; Digital loan/M-Shwari	Increased per capita consumption and savings and reduced poverty rates; Improved household resilience
	Wieser et al., 2019; Munyegera and Matsumoto, 2016	Uganda	Mobile money (with rural agents)	Reduced transaction costs, increased self-employment, and reduced food security. No effect on saving, agricultural outcomes, and poverty; Improved household welfare
	Riley, 2018	Tanzania	Mobile money	Provided insurance against rainfall shocks, resulting smooth consumption
	Batista and Vicente, 2020	Mozambique	Mobile money	Increased saving and investment in modern agricultural technology
Agricultural market data collection, crowdsourcing services, and big data	Alulu et al., 2020	Kenya	Digital crowdsourced platform /KAZNET	Near real-time and reliable market data from remote areas
	Adewopo et al. 2021; Solano-Hermosilla et al., 2022	Nigeria	Mobile-based crowdsourced platform; ODK-based food price crowdsourcing with behavioral nudge	Near real-time price information during the covid-19 pandemic; Nudges that capitalize on social norms (as opposed to information disclosure) increased the number of submissions.

Source: Authors' compilation.

that digital tools can have impact. The most powerful illustration of this comes from the lockdowns introduced in many African countries to contain the spread of the COVID-19 pandemic. Although these lockdowns disrupted agricultural supply chains and markets in many countries, digital tools were used in some countries to maintain critical logistical and financial services, ultimately keeping agricultural inputs and commodities moving and markets functioning (GSMA, 2021, 2020; Fernando, 2020; Chakravorti et al., 2020).[6] There is already emerging evidence to indicate that value chain actors using digital solutions in their operations prior to the pandemic were less affected by the shock (e.g., Abay et al., 2020).

Finally, prior studies explore how digital innovation can *improve data collection, analysis, and dissemination,* especially when driven by machine learning, artificial intelligence, cloud computing, remote sensing, and the internet of things (Galaz et al., 2021; Das Nair and Landani, 2020). These tools provide functions critical to the underlying infrastructure and organization of markets as well as the policies and regulations required to ensure smooth market operations and healthy competition (e.g., Solano-Hermosilla et al., 2022; Adewopo et al. 2021; Alulu et al., 2020). Big data tools and applications, for example, can support real-time tracking of livestock, the movement and delivery of inputs, machinery, and inputs and commodities, the identification of market disruptions – road closures or power cuts – and potential remedies, or monitoring and forecasting market patterns and trends. That said, there is scant evidence of the impact of this pathway to date.

In sum, our review of the conceptual and empirical literature on digital innovation in Africa's agricultural markets suggests several important points. First, the body of evidence is still growing. While there are many studies on market advisory and information services, there are relatively fewer studies on digital tools for market linkages and for financial services and transactions. Even fewer studies explore the impact of agricultural market data collection, crowdsourcing services, and big data. Second, there are multiple and intersecting impact pathways and many context-specific factors that will challenge efforts to rigorously evaluate many of the digital tools. This should not imply that rigorous evaluation is impossible, but rather that the design of these evaluations must accommodate multiple theories of change and disentangle complex impact pathways and mechanisms to explain outcomes (or the absence thereof). Third, and possibly more important than these other points, our review finds that most of the empirical evidence is built

[6] The Global System for Mobile Communications Association (GSMA, 2021) report notes that with traditional extension being challenged by lockdowns and social distancing, most market advisory services shifted to digitized delivery. Farmforce in Cote d'Ivoire, Tanzania and Rwanda and Farmerline in Ghana and Cote d'Ivoire are both examples of digital tools that added COVID-19 advisory to their services (GSMA, 2020). Digital financial services have also been in high demand during the pandemic.

on evaluations of small-scale case studies, pilot projects, and experiments. Fourth, there are not many studies evaluating and comparing the efficacy of alternative modalities of ICT services (e.g., radio, IVR, SMS and mobile application) to support the functioning of markets (Giulivi et al., 2022). Finally, there is a surprising lack of documentation on scaling experiences in the digital innovation space. We explore this latter topic further in the next section.

5. What explains the disconnect between pilots and scale-ups?

Digital innovation readily lends itself to rigorous evaluation: it is relatively easy to randomly assign digital treatments and compare outcomes to non-digital controls or variations in the treatment (Spielman et al., 2021). But most studies to date remain narrow, confining themselves to the evaluation of small-scale pilot interventions and very proximate outcome indicators, such as changes in farmer awareness and knowledge about agricultural technologies and practices, subsequent uptake and adoption decisions, and profit or income effects, typically over very limited temporal, and geographical scales (e.g., Abate et al., 2023; Van Campenhout et al., 2022). Few studies systematically examine market-level impacts, including impacts on input market channels, supply chain and network performance, or effects on costs, prices, and returns (Table 2). The lack of nuanced evidence and experience from both successful and unsuccessful scaling efforts impedes the types of learning that may guide future scaling efforts.

This near absence of nuanced evidence and experience relates to several factors, including the possibility that it may just be too soon, as noted earlier. But given the broad interest and enthusiasm for digital innovation in African agricultural markets, it is worth pointing out that there exists a significant gap between interesting pilot projects and successful scale-ups in Africa's digital innovation space (e.g., World Bank, 2016; Fabregas et al., 2019b; CTA, 2019; Steinke et al., 2021). In fact, the persistence of small-scale pilots in the digital innovation space combined with the limited evidence of widespread use may point to a larger challenge (Table A1). It may be the case that many pilots are simply not scalable. We explore this possibility by identifying several supply- and demand-side constraints to scaling that may warrant greater attention.

5.1. Potential supply-side constraints to scaling

The first constraint to consider relates quite simply to insufficient public and private investment in digital innovation. Efforts to scale digital tools to a point where they fundamentally transform African agricultural markets require considerable public investment in infrastructure and talent—investments that often have public goods attributes and thus can only be supplied by governments. At the same time, the scale-up of these innovations requires a certain degree of public sector withdrawal from the market so that input and commodity suppliers can compete and leverage digital innovation to reduce their costs and secure competitive advantages. In many countries, a statist role in price management and value chain development tends to limit these opportunities.

Meanwhile private investment in digital market-related technologies may be constrained by such factors as significant initial cost, non-appropriability of added value, and long lag times to profitability. Just as few African governments have the resources necessary to make long-term investments in soft and hard infrastructure, educational system improvements, or digital innovation incentives, few private entrepreneurs and investors have the financial capacity or risk appetite to innovate beyond a very short time-horizon. While external donors – bilateral and multilateral funding agencies, international development organizations, and charitable foundations – may have greater capacity to incubate digital innovators and invest in soft infrastructure, their own priorities and attentions often shift too quickly to stay the course.

The second constraint relates to the *asynchronous pace of change*. Rapid progress – the oft-cited leapfrogging effect (e.g., UNCTAD, 2019; Stephenson et al., 2021) – in the digital innovation space has not been accompanied by transformations in agricultural systems in many parts of Africa. In effect, the pace at which digital innovation brings solutions to agricultural markets in Africa is not being matched by changes in the rate of agricultural transformation – in productivity, capacity, or efficiency – that are needed to support and sustain these digital technologies (see, e.g., CTA, 2019). Instead, agricultural market transactions continue to be undertaken in environments characterized by isolation, limited scale, and risk (Benami and Carter, 2021). In short, the absence of sufficient surplus farm production, value addition opportunities or prospects for market arbitrage may simply not yet be available in many countries and contexts.

A third constraint to scaling relates to the *embeddedness of innovation*. Ideally, digital tools and technologies perform best when they are embedded within a wider innovation process that integrates R&D with markets through knowledge brokers, financial investors, and risk-loving entrepreneurs, all within a conducive business environment and regulatory framework. This is the science of scaling, characterized by strategies in which innovations contribute to and become embedded in broader processes of systemic change (Wigboldus et al., 2016; Sartas et al., 2020; Schut et al., 2020). Instances of where all the required elements for scaling converge are still few and far between in many African agricultural markets. For example, many countries still lack comprehensive and dynamic digitalization policies or regulatory frameworks to support digital innovation in the agriculture sector. Indeed, some countries in Africa have policies and frameworks that stifle and discourage digital innovations, e.g., banking/mobile money regulations in Senegal and Ethiopia, which stands in stark contrast to the more supportive regulatory frameworks in Kenya and Ghana. A lack of clarity in regulatory frameworks is also limiting cross-border spillovers and the scaling of digital innovations from one African country to another (CTA, 2019).

Finally, most companies investing in digital technologies to support agricultural transformation in Africa are still struggling to develop *sustainable business models,* partly due to the incipient stage of market development, i.e., lower demand at early stage resulting in higher unit costs of service provision. The lack of sustainable business models tends to limit the reach and scale of digital tools to support markets and marketing of agricultural products and services in Africa. Digital tools funded by donor organizations, in particular, are struggling to ensure a healthy balance between generating impact and establishing financial sustainability. For instance, AGRA (2016) attributes the failure of many agriculture-focused digital innovations and start-ups in Africa to the lack of viable and financially sustainable business models, partly because smallholders have limited ability and willingness to pay for digital services.

5.2. Potential demand-side constraints to scaling

The issue of ability and willingness to pay for digital services leads us directly to the issue of demand-side constraints. Here, our review finds that the scaling of many of the digital tools being developed in or for African agricultural markets are constrained by the absence of context-specific analyses that are critical to understanding demand for a given product or service. Many pilots tend to be "app-based" solutions where the technology comes first and the context-specific demand analysis comes later, if at all. This is not uncommon in both entrepreneur-driven startups and researcher-driven experiments that aim to revolutionize or disrupt agricultural market information systems with digital tools, many of which emerge without sufficient understanding of local market constraints, pre-existing local information systems and networks, or how these systems and networks can be complemented or integrated with digital tools. In the absence of contextual understanding, new information systems can be alien to farmers and other agents, or disruptive to markets that were already efficient within the bounds of extant

institutions and context. As a result, studies often show that smallholders are not willing to pay the full cost of digital tools and services. For example, Cole and Fernando (2021) show that although IVR services in India increased farmers' income and associated returns to investment, they are only willing to pay a fraction of that return. Subsequent work by Fernando (2021) find that mobile phone-based extension advice succeeded because it encouraged peer interactions and information sharing – very conventional impact pathways that are often overlooked in the value propositions prepared for many digital tools.

Similarly, our review finds that the scaling of many of the digital tools is constrained by a lack of clarity on inclusion, or the provision of products and services to marginalized groups – smallholder farmers, women and youth farmers, farmers in marginal agro-ecological zones – that may represent a majority of participants in agricultural markets. Little is documented on digital inclusiveness in Africa's agricultural markets, although the working hypothesis is that digital entrepreneurs and service providers are likely to target easy-to-reach customers at the pilot stage to establish proof of concept and viability, without investing significantly in inclusion strategies at scale (see, e.g., CTA, 2019). Ironically, digital tools may actually generate greater impact among marginalized smallholders, including women, poorer and remotely located farmers, when compared to those who may already be better integrated in agricultural markets. Indeed, the digital divide in Africa's agricultural markets is a significant factor: less than 40 percent of smallholder households have access to the internet, with such access increasing with farm size (Mehrabi et al., 2021). Women farmers have even less access to the internet and mobile phones (Mehrabi et al., 2021). Given the lack of evidence, it is not immediately clear whether efforts to scale digital tool are able to address this issue or are actually constrained by it, although some studies suggest this possibility (e.g., Cole and Fernando, 2021; CTA, 2019).

Next, accessibility and usability of digital tools should be considered when assessing constraints to scaling. CTA (2019) shows that while registrations of digital services are increasing, usage remains low. Digital literacy may be an important limiting factor: the CTA (2019) study finds that 28 percent of digital technology enterprises report consumer-level digital literacy as an important barrier to adoption and use of digital tools. This suggests a disconnect between digital tool design and testing among diverse user-groups, recognizing that smallholders are quite heterogenous, varying in positionality, not only in terms of geographical location but also in socioeconomic circumstances, human capital (e.g., literacy and numeracy), and social structure (e.g., facing different social norms around access to digital technology).

User confidence in digital tools is another important but understudied topic that may explain the lack of scale in digital innovation. Aker et al. (2016) highlight trust, in the sociological sense of the term, as an essential element that may determine how digital tools are accepted, received, interpreted, and acted upon. For example, Molony (2008) argues that although ICTs facilitate transmission of market information across agents in Tanzania, they could not build the trust needed between agents, which is critical for executing transactions. Smallholders are more likely to use or rely on digital tools if they believe that the information it provides comes from a trustworthy source, is timely and high-quality, and is tailored to meet their needs. Perceptions about input quality has been shown to be a strong factor adoption of technologies (e.g., Michelson et al., 2021; Ashour et al., 2019), so it is entirely reasonable to assume that similar perception issues may affect user demand for information products.

6. How to harness digital solutions for African agricultural markets at scale?

Ultimately, efforts to reap the full potential of digital innovation in African agricultural markets may require more than just novel apps and small-scale pilots. As argued by List (2022), to ensure widespread and transformative impact these innovations should achieve "high voltage", the ability to be replicated at scale. In this section, we suggest several steps to harness digital innovations at scale to make agricultural markets in Africa more vibrant, competitive, and inclusive.

A first step in this direction is to address the *human capital* constraints that impede both the creation and utilization of digital tools (Jellason et al., 2021; Birner et al., 2021; Kim et al., 2020; Malabo Montpellier Panel, 2019). The vast majority of existing digital agricultural marketing tools in the continent offer a limited range of solutions and lack novelty. This may be partly attributable to insufficient human capital in the ICT sector in Africa. Thus, there is a clear need to cultivate an ICT workforce and develop a cadre of technical and professional workers with advanced ICT skills and entrepreneurial capabilities. Besides formally training large volumes of workers with ICT skills, governments and other stakeholder in this space can play a pivotal role by establishing innovation hubs and ICT business incubators; providing competitive grants, innovation prizes, and other incentive programs; and support local technology networks that link directly to public investments in the agricultural sector.

A concurrent step is to invest in the human capital of users, especially farmers, rural entrepreneurs, and other actors who may have limited digital literacy or numeracy because of factors such as age, education, gender, or opportunity. Investment in the digital literacy of users such as rural students and young farmers is equally important given that they may be more aware and more likely to adopt digital tools if targeted appropriately. Further, it is important to keep in mind that even with large-scale digital literacy campaigns and education programs, many farmers may remain unfamiliar or uncomfortable with digital innovations. For example, there may be many instances where farmers prefer analog solutions such as talking to a market agent over the phone, even when the service they dial into may be digitalized on the back end. This calls for significant adaptation of digital innovations to ground realities such as low levels of digital literacy among end-users or preferences for simple and intuitive interfaces (Daum et al., 2021; Trendov et al., 2019). Examples include digital tools that integrate local in-person agents, voice recognition functions, or chat bots to help users complete lengthy registration processes or navigate complex menu options. Several of the digital tools reviewed earlier integrate these features, including Hello Tractor in Nigeria, which uses live booking agents and phone calls to provide services to its clients, and Lersha in Ethiopia, which uses similarly local agents to help farmers access their digital services.

A second step is greater public and private investment in the *complementary infrastructures, both tangible and intangible,* that are required to scale digital innovation in Africa. Tangible infrastructures such as stable internet connectivity, sufficient bandwidth, wide mobile network coverage, secure server access, and electrical power are all critical to increasing the usability of the hardware and software required by these digital tools. Often, these tangible infrastructures require significant public investment because remuneration to private investors is either insufficient or results in inequitable distribution of benefits. Equally important are investments in intangible infrastructure such as agricultural data ecosystems that generate site-specific, spatially explicit crops, soil, land, weather, post/disease, and market data, and integrate these data with farmer registries, weather data, and other data streams. Similar to tangible infrastructures, these intangibles often require public investment given their significant initial costs, non-appropriability by private actors, long time lags to profitability, and other characteristics (Kim et al., 2020; CTA, 2019). That said, both tangible and intangible infrastructures can be procured through the public procurement of private services, public–private partnerships, or other mechanisms, especially where private sector expertise and experience outweighs government capacity in the digital space, as is often the case (FAO, 2019; Baumüller, 2018).

A third step towards scaling digital innovation and realizing their full potential for transforming African agricultural markets requires the development of *innovative and sustainable business models* for private

entrepreneurs in the digital space. Currently, the vast majority of digital solutions providers not only rely heavily on public—particularly *donor*— funding, but actively seek public funding for their projects under the auspices of development assistance, rather than seek private funding based on credible revenue-generating models. More effort is required in the development of revenue models based on the sale of subscriptions or memberships or fee-based services to farmers, which otherwise seem to be few and far between. While donor funding can be instrumental at the pilot stage, it is unsustainable at best and, at worst, can be market distorting at the scaling stage.

This should not imply that digital innovation can or should be fully privatized. Public funding will remain crucial in the early stages of digital innovation, especially when a digital tool on offer has strong public goods characteristics, or its use is severely constrained by users' strong preferences for the status quo or their limited purchasing power, or where the benefits may contribute to the broader productivity or welfare of a community beyond the individual user (Hidrobo et al., 2020; Birner et al., 2021; Fabregas et al., 2019a). Thus, there may be good reasons to sustain public funding of call centers and IVR services for farmers like the 80–28 IVR Hotline in Ethiopia or NamLITS in Namibia, among other examples.

But the persistence of market distortions induced by public (and donor) funding suggests a need to quickly push digital providers towards clear business models and profitability pathways, or else walk away and invest in other, more traditional market development projects. One such pathway to profitability may be the bundling of public goods and services with other profit generating complementary products or services to cover the costs of information creation and distribution. An example of this approach is xarvio Digital Farming Solutions, in which an input provider finances a sophisticated digital platform that serves both farmers and contractors. Along the same lines, DigiFarm and iCow in Kenya finance their operations through network providers who have an incentive to increase subscribers and ensure customer loyalty in addition to providing agriculture market-related services. However, many of the previous attempts to finance digital services by selling subscriptions to farmers have only reached a small fraction of the potential market (Fabregas et al., 2019a; CTA, 2019). Fabregas et al. (2019a) argue that the nonrivalry and non-excludability nature of these services/tools can limit the success and sustainability of these subscription-based models.[7] But apart from these examples and a few others, the absence of commercially viable bundled services may be attributable to the costs and complexity these arrangements may entail. Fully functional, digitally integrated services entail much more significant investments than, say, a simple app that matches buyers with sellers. Unfortunately, the digital ecosystem in much of Africa currently favors simple apps and adaptive innovation over complex commercial solutions that require novel and intense design processes, though that may be changing rapidly.

A fourth step is for countries in Africa to develop *complementary agricultural input and output markets and supporting services* in order to make the information/services provided by digital platforms actionable. The utility of market information and marketing facilitation services may be limited in the absence of well-developed input and output markets – a characteristic which is still prevalent in many parts of the region (Ariga et al., 2019; Schut et al., 2016). Of course, digital marketing platforms themselves may also support this process through integrating functions that facilitate the matching of demand with supply in agricultural input markets. For instance, digital platforms can generate input demand data that can be shared with potential suppliers, track input availability, and notify farmers when inputs are in stock with dealers in their locality, even making it easier for farmers to check and compare prices (Fabregas et al., 2019a). But digital tools alone are unlikely to solve market gaps; broader policy attention to strengthening input market function will remain important.

The fifth step is the creation of *dynamic policies and smart regulations* that can: spur digital innovations as well as safeguard competitive markets, ensure equitable distribution of digital dividends, address privacy concerns, and promote good data stewardship (Kira et al., 2021). Currently, countries with a dedicated policy for agricultural digitization are scarce in the continent and or fall short at the implementation stage, thus limiting the production, distribution, and uptake of digital technologies and services (Nakasone and Torero, 2016; Korovkin, 2019; Tossou et al., 2020; Ayamga et al., 2021). Moreover, policies need to embrace digital solutions beyond individual projects and create institutional space for flexible and data-driven decision-making (Steinke et al., 2021). Regularly updating digital polices to keep pace with the dynamic needs of the digital ecosystems is equally important. The digital-friendly policies and regulations in Kenya and Ghana that led to the rapid expansion of their digital ecosystems are examples that other countries can emulate or adapt (e.g., Mercy Corps et al. 2021).

Last but not least, countries should deliberately facilitate the creation of *strong alliances among digital actors*. Existing digital initiatives which are fragmented in most countries results in under-utilization of complementarities and synergies, and could sometimes cause undue duplication of efforts. A well-coordinated partnership among digital actors (including user-group representatives) can facilitate investment, innovation, and scaling (Kim et al., 2020). Such alliances can be instrumental in the cost-effective development of shared infrastructures such as agricultural data ecosystems and standardized ontologies for data collection. The experience from Kenya is a good example, highlighting the key roles that partnerships among digital actors can play in facilitating innovations. That said, alliances should be built with care so as to preserve competition in the market and to prevent the emergence of efficiency-reducing market power and industry concentration.

7. Encouraging trends and emerging risks

Already, there are encouraging trends suggesting that many of the right steps are being taken across Africa to encourage digital innovation in agricultural markets. Ecosystems of small start-up enterprises are emerging in multiple countries, and governments are easing restrictions on the movement of talent from the African diaspora and between African countries to facilitate these enterprises. In several countries, tech incubators and developer hubs appear to be thriving, for example, Kenya's Silicon Savannah, South Africa's Silicon Cape Initiative, and Nigeria's Wennovation Hub, the latter hosting an explicit program for agri-tech startups. Meanwhile, many of the necessary infrastructure investments are being made, albeit within the limits of public budgets that are stretched thin across multiple development priorities. Partly as a result of these investments, growth in Africa's digital connectivity is expected to continue increasing in coming years, giving increasing scope for economies of scale in service provision. Between 2020 and 2025 the percentage of households in sub-Saharan Africa with SIM connections is expected to rise from 77 percent to 90 percent, and smartphone adoption is expected to increase from 48 percent to 64 percent (GSMA, 2021b).

However, there remain certain types of constraints that are not easy to overcome with strategic investments in human capital, infrastructure, and policy reforms. The most significant among these may not be the dispersed and fragmented nature of smallholder agriculture, but rather the persistence of non-competitive market structures and the unequal distribution of market power, a concern we alluded to earlier. Monopsony and monopoly market structures are a common historical feature in agriculture throughout much of the world: state-owned enterprises, commodity boards, colonial-era export monopolies, and other anti-competitive institutions were ubiquitous in agricultural markets

[7] Some other business models involved selling advertising and partnerships with profit-oriented commercial entities. However, these type of models and profit-maximizing intentions may affect the quality and objectivity of services offered (Anagol et al., 2017; Fabregas et al., 2019a).

during Africa's colonial and post-colonial eras. Traders, middlemen, plantation owners, commission agents, politicians, and administrators are often positioned to exert control and power over smallholders using a wide range of anti-competitive market mechanisms (and other, more persuasive, and coercive mechanisms) to extract resources from rural areas for the benefit of export and urban markets.

Today, new forces may be sustaining or even expanding these anti-competitive forces as novel forms of political capture and rent seeking that enable anti-competitive strategic behavior across multiple value chains. It remains to be seen whether digital innovation can push markets towards greater competition by, for example, improving farmers' access to information about price trends or their outside options in less-than-favorable obligations under formal or relational contracts. In fact, it may be the case that digital innovations have little value in instances where powerful actors can prevent their adoption, or when those same actors can simply dictate terms to farmers irrespective of the information or services offered by the digital innovation. Even disruptive innovations with the potential to shake the foundations of a captured market – something similar to, say, ride-sharing apps that threatened the market power of public transport regulators, taxi monopolies, and driver unions in some industrialized countries – are unlikely to survive if sufficient political force is mobilized to thwart their development.

When agricultural markets are non-competitive and when powerful forces have outsized influence over both agricultural markets and digital spaces, there is also a potential threat to privacy. Farmer registries – mentioned earlier as a potentially essential part of a functional digital ecosystem – may also serve as control systems for governments. With information on a farm-household's demographic profile, landholdings, assets ownership, crop mix, and other characteristics, governments are well-positioned to dictate production and marketing decisions that may be beneficial to national food security or export promotion strategies, but unprofitable for the individual farmer. In effect, the collection and use of personal data can encourage latent tendencies of governments towards central planning that ultimately rob farmers and other value chain actors of the ability to make decisions in their own best interest. This is not a benign threat: already, some governments in Africa have made considerable strides in this direction with support from donors, the private sector, and other entities.

Another point that merits some discussion is the need for digital tools to achieve a critical mass in user participation and enable their services to flourish and sustain. As an example, applications that connect buyers and sellers will not work well without a sufficient number of potential transacting partner options. If options are too thin, price signaling may be muted, and transaction characteristics (in terms of location, volume, quality standards, and so on) may be too limited to attract either buyers or sellers. This was an early challenge for the ECX in Ethiopia, which was overcame only when coffee was added to its list of traded commodities. But creating sufficient volumes may be difficult in early stages of market development, so it is not immediately clear what public support strategies may help overcome these hurdles without compromising competitive market characteristics.

8. Conclusions

A great deal has been said in recent years about the potential for digital tools to transform agricultural marketing in Africa. In particular, the possibility that ICTs can overcome information asymmetries, transactions costs, coordination failures and other limitations of thin and fragmented agricultural markets has motivated considerable investments in market-oriented tool development. However, empirically grounded discussion of the performance and scaling experiences of ICT-enabled agricultural marketing tools has been limited to date. In this review, we synthesized available evidence on the characteristics of ICT-enabled marketing innovations and tools, their deployment, impacts, and efforts to scale.

A major conclusion of our review is that, while many digital tools for agricultural marketing have been developed and deployed in recent years in Africa, the vast majority of these have been implemented at pilot stages, with limited evidence of successful scaling, let alone impacts on agricultural market performance. There is a strong need to systematically capture scaling experiences – including failures – in order to better understand the critical features of viable scaling strategies in different contexts. The current lack of nuanced evidence from both successful and unsuccessful scaling efforts around agriculture-focused digital tools in Africa is impeding learning which may guide future scaling efforts. Relatedly, evaluations of tool impacts will require not only measurement of changes in farmers' knowledge, technology adoption patterns, or productivity outcomes – as is typically the case in program evaluation efforts – but also longer-term and broader market-level impacts, such as value creation and value chain efficiencies, as well as higher-order impacts related to welfare and equality. In other words, internal validity concerns should not obscure the need for studies with plausible external validity.

A second major takeaway from our analysis is that the marketing and related institutional characteristics of Africa pose some important constraints for the development of agricultural marketing tools. Non-competitive market structures and the unequal distribution of market power remain prevalent characteristics in much of the region. The rapid rollout of digital innovations has outpaced infrastructural and institutional change in most of the region. Without committed policy attention to improved business environments, digitalization policies, and regulatory frameworks, the scope for a private sector-led expansion of digital tools will likely remain limited.

A third and important conclusion is that there are substantial differences in progresses across African countries in tapping the potential of digital tools, as well as substantial differences in access to and use of digital innovations across communities and households on the continent. While some African countries have made significant strides in building digital spaces for agricultural markets (e.g., Kenya and Ghana), weak internet infrastructure and regulatory frameworks in many African countries will likely continue to inhibit widespread scale up of digital innovations in the next few years. Furthermore, our synthesis shows that the differential access to internet and mobile phones across farmer types and gender dimensions may be exacerbating the digital divide. This necessitates investments and policies to ensure digital inclusion of marginalized households and communities.

Our analysis can be taken as a gentle corrective to the sometimes-unbridled enthusiasm that has accompanied the advent of digital agriculture in Africa. Importantly, our assessment of the current situation is still consistent with a fundamentally optimistic view of the possibilities for ICT-enabled digital tools to support transformative change in Africa's agricultural markets. The challenges we highlight are all surmountable. However, policy reforms and investments should be informed by careful analysis of what works, in turn enabled by better data collection on the innovations now in the field. This implies, at minimum, better coordination amongst national governments, donors, and project partners, to more systematically generate and pool comparable information about scaling efforts. The potential payoff to such efforts, however, may be considerable, i.e., faster, and more efficient scaling of marketing tools that can significantly improve the livelihoods of Africa's smallholder farmers.

In sum, realizing the promise of digital technologies to transform African agricultural markets is likely to require much more investment and learning from successful and unsuccessful scaling-up efforts. This means overcoming the paucity of empirical evidence on what works where and under which conditions in terms of design, content, scaling strategies, financing, and enabling policy and institutional factors. More systematic and comprehensive evaluations of existing initiatives may help to shape more effective modalities and partnerships to ensure sustainable delivery of digital marketing services in agriculture. These same evaluations may also contribute to addressing institutional constraints that inhibit the mainstreaming and integration of digital tools

into national agricultural marketing systems and practices.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodpol.2023.102439.

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