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Working Paper 214

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Documenting the digital transformation of African agriculture:
Use and impact of digital technologies among agricultural intermediaries

ISSN 1864-6638 Bonn, June 2022

PARI

ZEF Working Paper Series, ISSN 1864-6638
Center for Development Research, University of Bonn
Editors: Christian Borgemeister, Matin Qaim, Manfred Denich, Till Stellmacher and Eva Youkhana

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Documenting the digital transformation of African agriculture

Use and impact of digital technologies among agricultural intermediaries

Heike Baumüller, Ubi Ikpi, Emmanuel Tetteh Jumpah, Geoffrey M. Kamau, Alpha O. Kergna, Lawrence Mose, Abdoulaye Nientao, Rose Omari, Dayo Phillip, Beatrice D. Salasya

Abstract

Agricultural intermediaries perform important functions in the African food and agriculture sector. Digital solutions targeted at these intermediaries could improve their service delivery while helping digital agricultural (D4Ag) service providers cover the last mile to producers. To determine how to empower agricultural intermediaries with digital technologies, it is important first to understand how they are already making use of and are impacted by these technologies in their professional activities. To this end, data was collected through 1,571 in-person interviews with extension workers, output dealers and input dealers in Ghana, Kenya, Mali and Nigeria. The results show that intermediaries make extensive use of ICTs in their work, much more so than the low adoption rates of D4Ag solutions would suggest. Mobile phones clearly dominate the digital technologies, most commonly smartphones, which are often used daily. Three areas of impact can be identified. First, ICTs facilitate information sharing between intermediaries and other value chain actors which emerged as the main activity and benefit across the three groups. Second, ICTs facilitate networking among value chain actors. In the case of dealers, these networks are mainly used for two-way business transactions while extension agents take advantage of ICTs to interact and share information with a wide range of actors. Third, ICTs reduce transaction costs for input and output dealers through better access to information about buyers, sellers and prices, better timing of produce / input purchases, faster payments from customers and reduced travel times. Given the widespread use of ICTs among agricultural intermediaries, D4Ag service providers can capitalize on intermediaries' existing digital skills, technological capacities and digitally enabled networks to expand their reach, in particular to producers who are still not universally accessible via ICTs, but also to other actors in the African food and agriculture sector.

Acknowledgements

We would like to thank John Kieti, Felister Makini and Matthias von Bismarck-Osten for their insightful comments on a draft version of the report. We are also grateful to Seth Amboga, Martha Opondo and Japheth Wanyama for assisting in the data collection in Kenya, and to Richard Ampadu-Ameyaw, Rankine Asabo, Sylvia Baah-Tuahene, Godfred Frempong, Elizabeth Hagan, Abdalla Mahama and Johnny Owusu-Arthur for their support in data collection, analysis and report writing in Ghana.

This study was developed in the context of the Program of Accompanying Research on Agricultural Innovation (PARI), supported by the Federal German Ministry for Economic Cooperation and Development (BMZ).

Table of Contents

List of tables and figures

1 Introduction

High hopes have been pinned on digital agricultural (D4Ag) solutions offered by companies, government agencies, civil society organizations or other service providers to help overcome obstacles faced by African small-scale producers and thereby increase agricultural productivity and food security (FAO, 2018; Tsan et al., 2019). Such solutions provide digitally-enabled services to agricultural producers and other actors in agricultural value chains, such as mobile payments, supply chain management software, digital advisory services or e-commerce.[1] While many D4Ag solutions exist in Africa, uptake has been limited (Tsan et al., 2019), raising questions about the real potential of digital technologies to transform African agriculture. Low adoption rates have been attributed to low digital skills, poor technology infrastructure, and challenges related to the discoverability, usability and affordability of D4Ag services (Kieti et al., 2022). The Covid-19 pandemic, which began in China in December 2019 and rapidly spread across the world, was expected to give a boost to digitalization in African food and agriculture given widespread restrictions on travel, personal contact and business operations (Bashuna and Addom, 2020), but actual impacts remain poorly understood.

Many of the D4Ag solutions developed in Africa are targeted directly at small-scale producers, in part to replace traditional intermediaries, such as e-extension or virtual markets for inputs and output. At times, they are even promoted as a means to cut out the "middleman" (e.g. Adesina and Verkooijen, 2021; Ehui, 2018; Ordu et al., 2021). However, agricultural intermediaries, such as input dealers, output dealers and extension agents, perform important functions in the African food and agriculture sector. Digital solutions targeted at these intermediaries could help to improve rather than replace their service delivery. That way, digital technologies could benefit small-scale producers even if they do not use the technologies themselves.

To determine how to empower agricultural intermediaries with digital technologies, it is important to first understand how they are already making use of and are impacted by these technologies in their professional activities. Very little research has been carried out in Africa in this regard. To address this gap, this study is the first to comprehensively assess the use and impact of digital technologies among agricultural intermediaries in Africa. The article takes a broader perspective than existing research by focusing on digital technologies more generally, including but not restricted to D4Ag solutions as is often the case (e.g. Munthali et al., 2018; Payne and Willis, 2021; Tata and McNamara, 2018; Tsan et al., 2019). The article is also the first to assess the technological capacities and digital skills of agricultural intermediaries, and to offer initial insights on how the Covid-19 pandemic has changed ICT usage among these actors. The findings can help to inform the design of user-centred and problem-driven digital agricultural services in the future (Steinke et al., 2020).

The article addresses the overarching research question how the use of ICTs affects the ability of agricultural intermediaries to perform their professional activities. The article is structured as follows. Section 2 provides a review of the literature related to the use and impact of information and communication technologies (ICTs) among agricultural intermediaries in Africa, with a focus on input dealers, output dealers and extension workers. Section 3 describes the methodology used in the study. Section 4 presents the results of the survey, including an assessment of intermediaries' level of digital skills, ICT use in professional activities and collective action, impact of ICT use on intermediaries' ability to perform their professional activities, and the influence of the Covid-19 pandemic on ICT use. Section 5 summarizes and discusses the results while Section 6 identifies implications for D4Ag service providers, and highlights limitations of the study and areas of future research.

[1] Digitalization for agriculture (D4Ag) has been defined as "the use of digital technologies, data and business model innovations to transform practices across the agricultural value chain and address bottlenecks in, inter alia, agricultural productivity, postharvest handling, market access, finance and supply chain management" (Tsan et al., 2019, p. 28). For the purpose of this article, D4Ag solutions refer to digitally-enabled services offered by a provider to agricultural actors.

2 Literature review

This section summarizes key findings from the available literature that provides empirical evidence on the use and impact of ICTs among agricultural intermediaries, including ICT use in general and use of D4Ag services in particular. In the context of this article, agricultural intermediaries include input dealers, output dealers and extension workers.

2.1 Input and output dealers

Much of the research on the impact of ICTs in African agriculture has focused on producers and less on other markets actors (Baumüller, 2018; Duncombe, 2016; Klerkx et al., 2019). In the early days of research on mobile phone use in African agriculture, several authors assessed the impact on agricultural output traders. All of these studies were carried out at a time when mobile phones were much simpler, more expensive to purchase and use, and not as widely adopted as today to create network effects. Aker (2010), for instance, finds that mobile phone use among grain traders in Niger led to a reduction in price dispersion by 10 percent, with larger effects in remote markets with higher transport costs. The researcher uses mobile phone coverage as the explanatory variable rather than asking traders how they are actually making use of their mobile phones.

Several studies examine the impact of mobile phone use on agricultural trading patterns in Tanzania (Molony, 2008) and Ghana (Boadi et al., 2007; Overå, 2006). They find that mobile phones reduce transportation and transaction costs by facilitating access to information about supply and demand, coordination of supply and keeping track of produce in transit. Overå (2006) also shows that ICTs enable traders to provide better services and achieve higher profits, in particular among larger wholesalers who could afford the cost of the mobile phone. At the same time, mobile phone use was found to have limited impact on trading patterns because these patterns are largely determined by existing trust relationships between trading partners as well as dependence of producers on credit from buyers. These studies are based on qualitative data and do not provide detailed quantitative data on ICT use and impact among traders.

Okello (2011) offers the most detailed account of ICT use among traders, focusing on Kenyan grain traders selling at the market. The majority of surveyed traders (82 percent) use ICTs for trading, primarily the mobile phone (79 percent of ICT users) and radio (21 percent). ICTs mainly serve to obtain information about the price, availability and quality of sold produce as well as prices in local markets, and to facilitate transactions. Many traders also feel that the use of the phone protects them against cheating by other traders. By far the main function used is voice calls while hardly any traders used SMS.

Regarding D4Ag services, input and output markets are often part of integrated digital platforms rather than stand-alone functions, along with other services, such as information provision or access to credit. Such multi-sided platforms facilitate business transactions between market players (von Bismarck-Osten, 2021). Depending on the level of vertical integration, they can be categorized as open, mediated and contract models (Mercy Corps, 2018). Open platforms offer only a space for, but do not directly engage in transactions. Mediated models get actively involved in the aggregation of supply and demand, but without contractual obligations. The third type involves entering into contracts with suppliers and offtakers. Platforms can combine these different approaches on both the supply and demand sides. For the purpose of this study, only platforms that support, but do not entirely replace input and/or output dealers are relevant. To the authors' knowledge, no empirical studies on the use of such platforms by input or output dealers in Africa are available.

2.2 Extension workers

Hardly any research has assessed the use and impact of ICTs in general among extension workers in Africa. One study in Ghana provides some insights on the use of different ICT tools by extension agents (Ayisi Nyarko and Kozári, 2021). All of the 153 extension agents surveyed make use of mobile phones and the vast majority use the internet and Whatsapp. Use of laptops (27 percent), tablets (18 percent) and desktop computers (12 percent) is less common. The main constraints to ICT use are weak network connections and lack of training. The authors do not specify, however, whether ICT use is for private or professional reasons. Data on actual usage of ICT tools suggests that extension agents use them primarily for private purposes. Just 9 percent of agents communicate agricultural extension information via ICTs while the large majority communicate with family and friends and watch entertainment programmes with the help of ICTs.

Research on the use of D4Ag services in extension is more common. The literature covers tools targeted at public or private extension workers to help them perform their tasks as well as tools to provide extension-like services. This article only focuses on the first type of tools where intermediaries are explicitly built into the design. One study examines the impact of using ICTs by so-called plant doctors, i.e. extension workers who provide farmers with practical plant health advice in the context of the program Plantwise (Wright et al., 2016). A survey of 60 such plant doctors in Kenya shows that the introduction of ICTs (tablets, mobile phones) has increased the speed, frequency and quality of advice. Plant doctors also use the technologies to collect information about plant pests and diseases.

Another study by Munthali et al. (2018) in Ghana compares the use of two ICT platforms, E-extension and SmartEx targeted at public and private extension workers respectively. Both platforms were hardly used by the agents. Instead, widely available messaging apps (e.g. Whatsapp, Telegramm) were more relevant for networking and information exchanges while weather forecasts were mainly obtained through the radio. The authors stress that traditional extension agents remain important as sources of information for many farmers due to the personal connection and a preference for face-to-face learning, thus highlighting the importance of ICTs as a means to support rather than replace relationships.

3 Data and methods

The research addresses the following question: "How does the use of ICTs affect the ability of intermediaries in the agriculture sector to perform their professional activities?". To this end, it assess the use of ICTs among intermediaries in their professional activities as well as the perceived impact of ICT use among intermediaries on their ability to perform these activities. Data was collected through in-person surveys carried out in Ghana, Kenya, Mali and Nigeria. The intermediary groups of input dealers, output dealers and extension workers were chosen because they deal most directly with producers and could therefore play a particularly important role in the digital transformation of the initial stages of agricultural value chains.

Kenya, Ghana and Nigeria were selected as study countries because they are among the leading countries in Africa with regard to digitalization in food and agriculture, exemplified by the relatively high prevalence of D4Ag services and high score in the Agricultural Digitalization Index (Table 1). Mali was added to include a country where digitalization in agriculture is expected to be less advanced. While mobile cellular subscription rates and 2G coverage are comparable to the other three countries, 3G networks are less widespread in Mali, especially in croplands (according to the Agricultural Digitalization Index). In addition, mobile broadband subscriptions are less common and mobile data are much more costly (as a share of GNI per capita).

Table 1: Selected Statistics related to digitalization and agriculture in the four study countries

	Mobile cellular subscriptions	Active mobile-broadband subscriptions	Internet users	Population covered by mobile cellular network	Population covered by at least 3G network	Mobile data and voice basket (low consumption)
	per 100 inhabitants		*% of population*			*% of GNI pc*
Ghana	130	85	58	97	96	2.6
Kenya	114	47	30	96	94	4.5
Mali	125	46	27	100	65	12.6
Nigeria	99	42	36	91	74	3.4
Source	International Telecommunication Union (2022)					
Year of data:	2020					

Table cont.	Agricultural Digitalization Index	Cropland covered by 2G	Cropland covered by 3G	D4Ag services
	Score	*% of cropland*		*Number*
Ghana	50.9	95.7	33.9	45
Kenya	48.8	89.2	42.9	95
Mali	33.6	32.5	3.8	10-19
Nigeria	46.2	92.3	9	47
Source	Schroeder et al. (2021)			Phatty-Jobe (2020)
Year of data:	2019 network coverage, 2017 cropland			2020

Three types of intermediaries were surveyed:

1. Public extension workers
2. Agro-output dealers, including market retailer/shops, market wholesaler, supermarket, aggregator/collector, producers' selling agents, farmer organisations, processors and exporters, as well as non-governmental institutions, government-based organization and farmers' organisation roles of output-dealers
3. Agro-input dealers, including market retailer/shops; market wholesaler, distributors, importer and input companies as well as non-governmental institutions, government-based organization and farmers' organisation roles of input-dealers

In each country, purposeful sampling was used to identify three districts / counties / regions (depending on the administrative structure of the respective country) representing diverse agricultural contexts in the country[2], based on factors such as agro-ecological characteristics, size of farms, number of farm households and production intensity. To identify respondents among the extension agents, lists were obtained from local authorities from which a random sample was drawn. Regarding input and output dealers, lists for random sampling were also obtained in Nigeria and Kenya while respondents in Ghana and Mali, where no such lists are available, were identified using random walk.

Since the focus of this research was to better understand how rather than whether intermediaries use ICTs, participation in the survey was restricted to respondents who either own a mobile phone or have access to one through someone else. In the end, this criterion did not have to be applied since the vast majority of potential respondents that were approached owned a mobile phone and the remainder had access to a mobile phone. In the case of output and input dealers, the owner or manager of the business was interviewed.

Table 2 shows the distribution of the sample by intermediary type and country. The data was collected using the same structured questionnaire in all countries administered through tablets by trained enumerators. In the case of Mali, the questionnaire was translated into French and the interview was done in the national language *Bamanankan*. The questionnaire was pre-tested in all four countries in March 2021 and the survey took place between April and July 2021.

For the most part, the results are presented using descriptive statistics. For selected variables, Pearson correlation analysis is used to explore the relationship between the variables. To account for the different sample sizes within intermediary groups between countries, the data were weighted using cell weighting for the purpose of the statistical analysis (see Table A1 in the Appendix). Unless otherwise indicated, N are provided as actual values while shares are computed using weights.

Table 2: Distribution of the sample by intermediary type and country

	Ghana	Kenya	Mali	Nigeria	Total
Extension agent	82	89	171	121	463
Output dealer	139	95	229	120	583
Input dealer	82	112	207	124	525
Total	303	296	607	365	1,571

[2] Ashanti, Greater Accra and Northern in Ghana; Nairobi / Kiambu, Tharaka Nithi and Uasin Gishu in Kenya; Koulikoro, Sikasso and Segou in Mali; South West and North Central in Nigeria.

The characteristics of the unweighted and weighted sample can be found in Table A2 in the Appendix. In the following only the weighted statistics are presented. The majority of respondents (69 percent) are between 30 and 54 years old. Overall, just over two-thirds of respondents (69 percent) are male, reflecting the unequal sex distribution usually found in these professions. Around a third of surveyed extension agents and output dealers are female while the share of women among input dealers is 27 percent. The sex distribution was most equal in Kenya (48 percent female) and least equal in Mali (9 percent female). Agro-output dealers in Ghana are the only group where women dominate (60 percent).

The level of education differs between the three groups of intermediaries. Extension workers have the highest level of education and almost all have completed post-secondary education (97 percent). The lowest level of education is found among agro-output dealers and respondents are almost evenly distributed between groups with no, primary, secondary and post-secondary education. Among agro-input dealers, three-quarters have completed at least secondary education.

Almost all respondents own a mobile phone (99.7 percent). Smartphone ownership is highest among extension agents (96 percent), followed by input dealers (80 percent) and output dealers (62 percent). Smartphone ownership is highest in Kenya (91 percent), followed by Mali (81 percent) and around 70 percent in Ghana and Nigeria. Overall, smartphone ownership rates among female respondents was only slightly lower than that of men (76 percent compared to 79 percent). Within intermediary groups, smartphone ownership rates are comparable among extension agents (around 96 percent) and input dealers 880 percent) while among output dealers 65 percent of male respondents owned a smartphone compared to 55 percent of women.

Most of the input and output dealers interviewed were market retailers/shops (72 and 40 percent respectively) and market wholesalers (21 and 36 percent respectively). Input dealers primarily sold pesticides (49 percent) and fertilizer (28 percent) as their main products. Most respondents (44 percent) listed maize as the main commodity grown by the producers they interact with followed by rice (11 percent) and vegetables (7 percent).

4 Results

This section presents statistics on the use of ICTs among intermediaries as well as (perceived) impacts of ICT use on professional activities. The survey took place during the Covid-19 pandemic in 2021. To assess the use of ICTs while excluding the effects of the Covid-19 pandemic, several questions differentiated between usage before and during the pandemic. The results presented in this section refer to the time before the onset of the pandemic, with the exception of section 4.3, which offers a comparison between responses relating to the time before and during the pandemic.

4.1 Use of ICTs among intermediaries

4.1.1 Digital skills

Respondents were asked a series of questions about their ability to perform different tasks on their mobile phone. The responses give an indication of their level of digital skills which can inform the design of D4Ag services. Where the respondents only used basic phones (9 percent of the total sample), the questions were restricted to the functions available on their phones. Overall, the majority of respondents are familiar with the simple features of their mobile phone, such as checking or topping up phone credit, or making and receiving phone calls (Table 3). The majority is also able to take photos if their phone has the required functionality.

Extension agents show the highest level of digital skills. They are able to perform on average 19 (out of 21) tasks with their mobile phone listed in the question, including using more sophisticated functions such as video calls, messaging apps and social networks. Digital skills are also high among input dealers who are familiar with 15 tasks on average, including more advanced functions, such as mobile money, SMS and messaging apps.

Output dealers show the lowest level of digital skills (12 tasks on average). While many are able to complete straightforward tasks on their phone, such as checking phone credit or making calls, they are less frequently able to perform tasks that require a higher level of skills or literacy, such as using GPS, connecting to WiFi, writing emails or filling in online forms. Nevertheless, around two thirds of output dealers were able to use SMS, messaging apps and mobile money while around half of them are able to use the internet and video calls.

Skill levels of male and female intermediaries are broadly comparable. Among extension agents and input dealers, male and female respondents are able to perform an equal number of tasks on average (19 and 15 respectively). Competencies differ among output dealers where men are able to complete on average 12 tasks compare to 10 among women.

With regard to the different types of skills, the ability to use D4Ag services is by far the lowest among all intermediaries. Even among extension agents who are very familiar with smartphone applications such as messaging apps, video calls or social networks, only 45 percent are able to use D4Ag services. Among inputs dealers, 28 percent are able to do so and among output dealers, the share is as low as 11 percent.

The averages across countries hide differences between countries, notably with regard to input and output dealers (Table 4). Digital skills among these two intermediary groups are highest in Kenya, followed by Nigeria. In Ghana and Mali, skill levels are comparably low among input dealers (12 tasks on average), while among output dealers they are lower in Ghana (8 tasks on average compared to 10 in Mali), the lowest skill level of all intermediary groups. Among extension agents, skill levels are comparable, ranging between 18 and 20 tasks on average.

Table 3: Digital skills among agricultural intermediaries

Do you know how to (use):	Extension worker	Output dealer	Input dealer	
Check phone credit	100	91	95	share of all respondents*
Top up phone credit	98	87	93	
Voice calls	99	99	99	
SMS	98	72	84	
Voice mail	86	47	70	
Mobile money	95	74	85	
GPS	86	25	42	
Photo	95	89	92	share of respondents using a phone with these functions**
Video	95	82	89	
Connect to WiFi	94	48	72	
Open an app	98	74	85	
Install an app	96	57	76	
Email	92	42	68	
Open a file on your phone	97	79	87	
Internet	96	56	80	
Online form	86	38	64	
Messaging app	98	70	89	
Video call	92	49	77	
Social network	92	61	81	
Digital ag services	45	11	28	
Other apps	39	16	25	
Average no. of tasks	19	12	15	

* Share of respondents within intermediary group and country (N = see Table 2)
** N (extension agents) = 456, N (ouput dealers) = 504, N (input dealers = 485)
Shares computed using weights (see Table A1)
Source: Authors' compilation

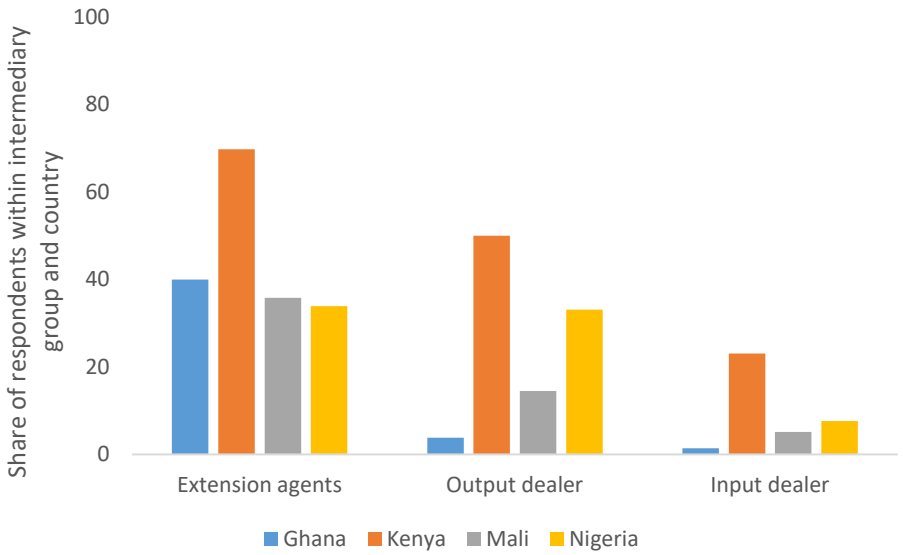
Table 4. Average number of tasks that intermediaries are able to perform by country

	Ghana	Kenya	Mali	Nigeria	**Total**
Extension agent	19	20	18	18	**19**
Output dealer	8	16	10	13	**12**
Input dealer	12	18	12	17	**15**
Total	**13**	**18**	**13**	**16**	**15**

N = see Table 2; averages computed using weights (see Table A1)
Source: Authors' compilation

Skill levels related to D4Ag services divert from these patterns. In particular among extension workers, abilities to use such services differ much more between the four countries than for overall skill levels. Thus, a considerably larger share (70 percent) of extension agents in Kenya are able to use such services than in the other three countries where the shares range from 34 to 40 percent (Figure 1). Among input dealers, only Kenyans show a certain level of skill to use D4Ag services while most of the dealers in the other countries are not able to use such services. Among output dealers, skill levels are highest in Kenya followed by Nigeria.

Figure 1: Skill to use D4Ag services by country and intermediary type (%)



Question: Do you know how to use a digital agricultural service?
N (extension agents) = 456, N (ouput dealers) = 504, N (input dealers = 485)
Shares computed using weights (see Table A1)
Source: Authors' compilation

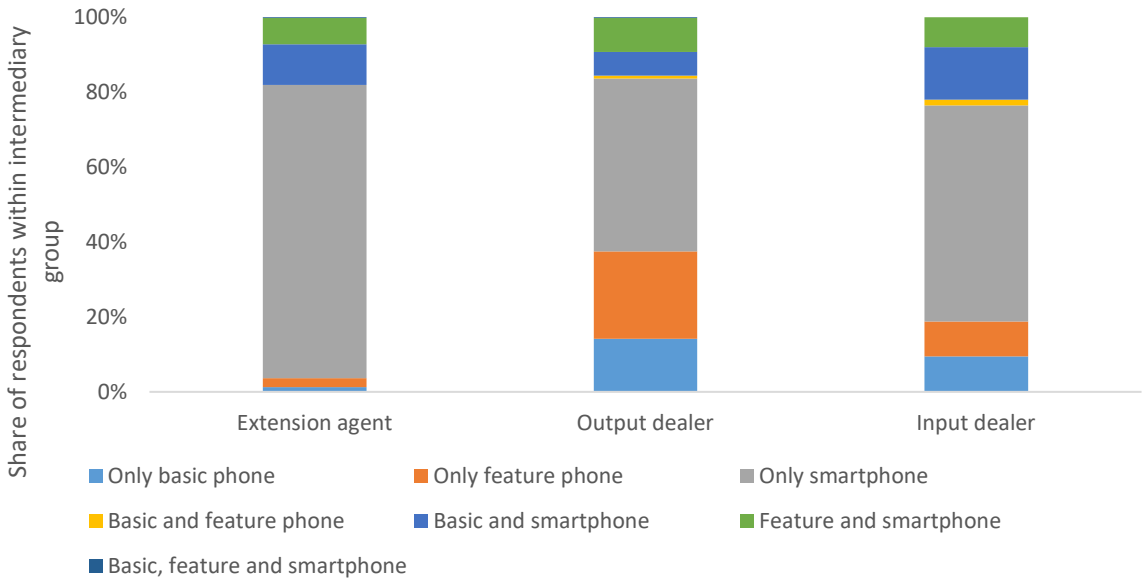
4.1.2 ICT use in professional activities

4.1.2.1 Type of ICT used in professional activities

All of the respondents make use of ICTs in their professional activities. The vast majority (99 percent) indicated that they use a mobile phone and almost as many (94 percent) listed it as the main ICT used. The majority of intermediaries use only one type of mobile phone. The differences in technological capacities between intermediary groups mirror the different levels of digital skills. Thus, smartphone use is most common among extension agents where over three-quarters list it as the only type of phone that they use in their work (78 percent). The share of smartphone users is lower, but still high among input and output dealers (58 and 46 percent respectively).

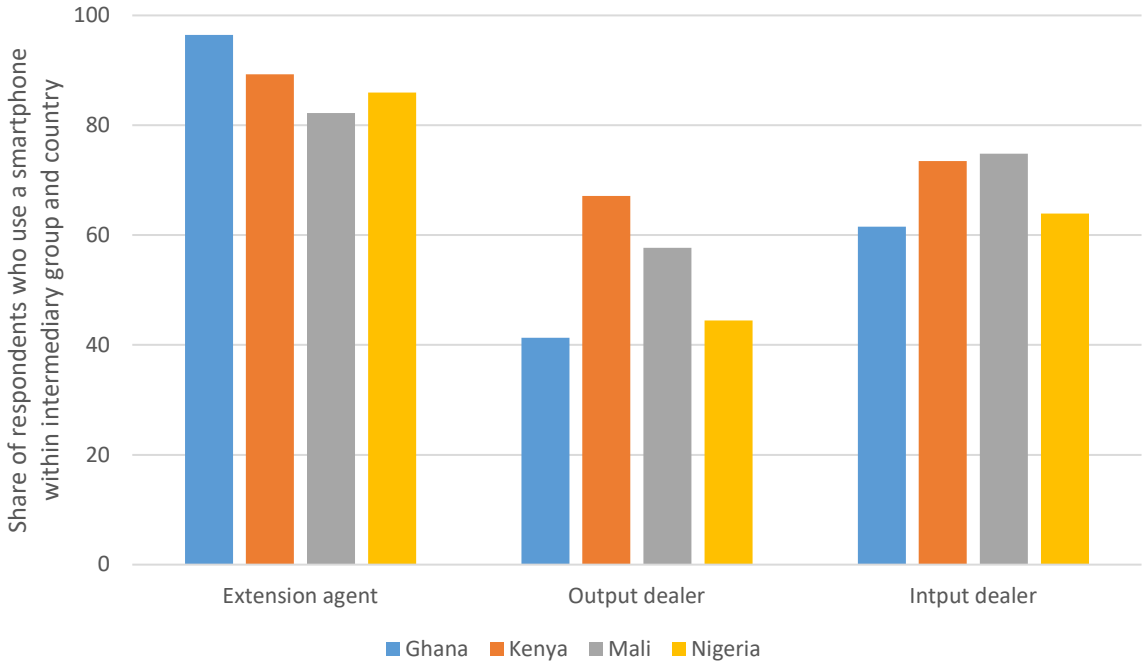
When comparing countries, smartphones use in professional activities is similarly widespread among the surveyed intermediaries in the four countries (though slightly lower in Mali and Nigeria). Difference can be observed with regard to output and input dealers, however, where noticeably fewer dealers in Ghana and Nigeria make use of this technology while the share is highest in Kenya followed by Mali (Figure 3). Use of feature and basic phones as the only mobile phone is highest among output dealers.

Figure 2: Types of mobile phones used by different intermediaries



N = see Table 2; shares computed using weights (see Table A1).
Source: Authors' compilation

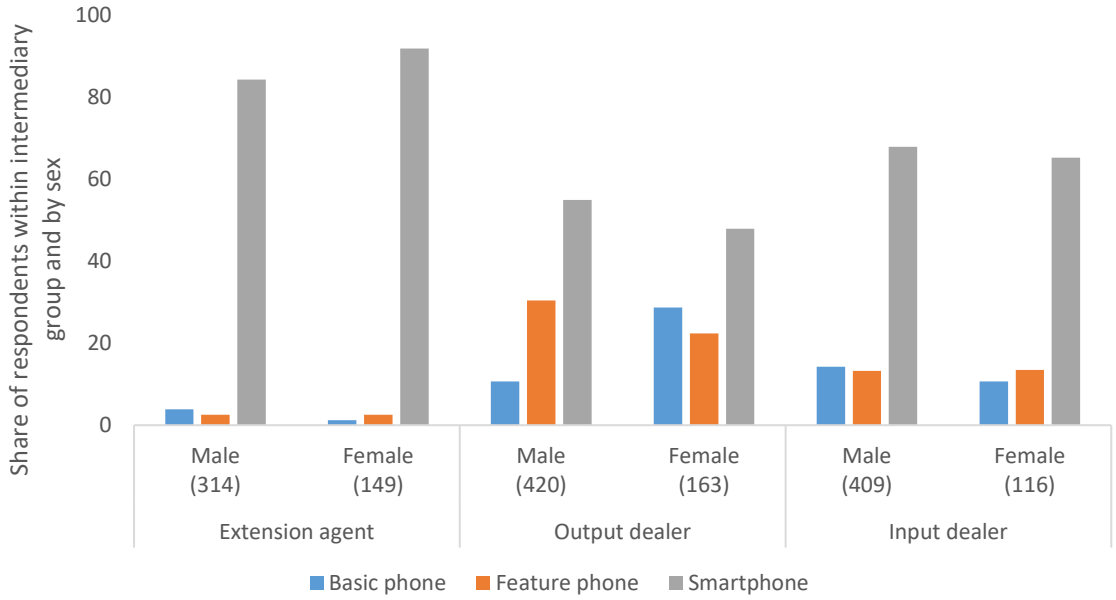
Figure 3: Prevalence of using smartphones as main ICT used in professional activities



N = see Table 2; shares computed using weights (see Table A1).
Source: Authors' compilation

Comparing ICT use by male and female intermediaries shows some similarities and some differences. Among output dealers, technological capacities among women is lower than among their male colleagues (Figure 4). While smartphones are most common among male and female output dealers, the share of basic phone users is considerably higher among women. In contrast, the frequency of using different types of mobile phones as the main ICT is comparable among extension agents and input dealers (with a slightly higher usage rate of smartphones among female extension agents).

Figure 4: Prevalence of using different types of mobile phones as main ICT by intermediary group and sex



N indicated in brackets; shares computed using weights (see Table A1).
Source: Authors' compilation

Other ICTs are less common than mobile phones. A sizeable share of extension agents and to a lesser extent input dealers are also using computers (48 and 20 percent respectively), but only around 5 percent use them as their main ICT. Radio and TV are used by only a few of the intermediaries (13 and 7 percent respectively) and hardly any name it as their main ICT. Irrespective of the intermediary group and type of ICT, almost all respondents make daily use of their main ICT.

4.1.2.2 Types of professional activities for which ICTs are used

Intermediaries were asked in which of their professional activities they use ICTs. The percentages indicate the share of intermediaries who had previously stated that they perform this professional activity. Data are only presented for those activities performed by more than 10 percent of intermediaries from that group since otherwise the sample size is too small to draw meaningful conclusions.

In general, ICTs are mainly and extensively used to perform the core functions of the intermediaries (Table 5). Dealers employ ICTs to buy and sell produce and inputs. Most output dealers use them to buy outputs from other output dealers or producers, as well as to sell outputs to consumers and other output dealers. ICTs are also widely used when arranging transport from producers or to buyers. Similarly, input dealers mainly use ICTs to facilitate transactions, including selling inputs to consumers and to other input dealers, and buying inputs from other input dealers. Of the few dealers who import inputs, the majority also use ICTs in the process.

Extension agents make use of ICTs for the widest range of activities. Most of them provide information to producers with the help of ICTs and conduct training, either with groups or individuals. Digital technologies are also used to connect producers to other value chain actors via ICTs, including input dealers and government officials (although only a small share of extension agents list this among their main professional activities while even fewer mention connections to output dealers).

Table 5: Main professional activities and prevalence of ICT use

		Main professional activity (top 3)	ICT use in professional activity	
		*Share of all intermediary group members**	*Share of those performing the professional activity*	*N*
Extension agent	Provide information to producers	85	95	388
	Conduct group training	72	79	328
	Conduct individual on-farm training	69	77	300
	Connect producers and agro-input dealers	12	70	50
	Connect producers and government officials	11	67	53
	Others**	10	67	52
Output dealer	Selling outputs to consumers	66	88	386
	Buying outputs directly from producers	53	92	307
	Buying outputs from other intermediaries	45	88	290
	Selling outputs to other agro-output dealers	32	88	224
Input dealer	Selling inputs directly to customers	95	93	495
	Buying inputs from other agro-input dealers	66	90	327
	Selling inputs to other agro-input dealers	43	87	237
	Importing inputs	11	84	63

*Share of respondents within intermediary group and country (N = see Table 2)
** ICTs are used in "other activities" for data collection, inspection and veterinary services (among others).
Shares computed using weights (see Table A1)
Source: Authors' compilation

4.1.2.3 Mobile phone functions used in professional activities

Respondents were asked which functions of their mobile phone they use in their professional activities (provided that they have the necessary device and skill to use that function). Extension agents make use of the largest numbers of mobile phone functions on average (9) compared to input (6) and output (5) dealers. Comparing responses across countries, intermediaries in Kenya and Nigeria make most diverse use of their phones (8 functions on average compared to 5 in the other two countries). The lowest number of functions used is found among output dealers in Ghana (3) and Mali (4).

While some functions are commonly used by all intermediaries, usage of other functions differs between the groups. Table 6 shows the prevalence of use of different functions both as a share of all respondents and as a share of potential users (i.e. those with the necessary skills and device). The table thus shows how widely the different functions are used in general, but also among those who are in fact able to use them. A comparison of these figures can provide some indication on the role of skills and utility as impediments to using different functions. D4Ag services are discussed in a separate section below.

Similar to the findings of Okello (2011) in Kenya a decade ago, voice calls remain by far the most commonly used mobile phone function among all intermediary groups, highlighting the continued importance of verbal communication. Most respondents are able to use this function and also make

extensive use of it, usually on a daily basis. In contrast to Okello (2011), however, other functions are now also widely used, likely due to the wider adoption of more sophisticated phones and reductions in costs of use. In particular extension agents and input dealers are using diverse functions of their phones, including the Internet, SMS and photo cameras. Many output dealers also make use of these functions, but less so.

Table 6: Mobile phone functions used in professional activities

	Extension agent			Output dealer			Input dealer		
	*Share of all**	*Share of potential users** (N)*	*Main function used**	*Share of all**	*Share of potential users** (N)*	*Main function used*	*Share of all**	*Share of potential users** (N)*	*Main function used**
Voice call	92	95 *(450)*	84	91	92 *(575)*	88	90	93 *(509)*	85
SMS	89	92 *(443)*	42	58	82 *(378)*	17	73	88 *(420)*	24
Mobile payments	61	65 *(432)*	4	68	93 *(413)*	46	74	89 *(434)*	40
Internet	89	94 *(435)*	18	37	78 *(256)*	4	57	81 *(359)*	8
Email	79	88 *(405)*	4	21	57 *(178)*	1	40	66 *(296)*	2
GPS	74	87 *(394)*	3	13	54 *(117)*	0	23	56 *(186)*	0
Photo camera	88	96 (*426)*	13	60	78 *(431)*	4	70	86 *(433)*	5
Video camera	82	88 *(431)*	1	46	65 *(395)*	1	56	71 *(416)*	0
Video calls	56	62 *(415)*	1	22	54 *(246)*	1	41	60 *(355)*	1
Text messaging app	80	84 *(441)*	15	38	64 *(343)*	9	60	77 *(411)*	13
Social network platform	62	70 *(409)*	5	31	60 *(283)*	2	50	69 *(363)*	2
Digital agriculture service	31	72 *(193)*	1	5	55 *(44)*	0	16	65 *(128)*	0
Other apps	6	16 *(158)*	0	1	9 *(60)*	0	2	7 *(101)*	0

Questions: Which functions of your mobile phone do you use in your professional activities? Which two [mobile phone functions] do you use most frequently in your professional activities?

* Share of respondents within intermediary group and country (N = see Table 2)

** Potential users include those with the skills and necessary device to use the function.

Shares computed using weights (see Table A1); Source: Authors' compilation

The results also highlight the importance of social media in professional activities, although they are still less commonly used than traditional communication channels like voice calls and SMS. Use of text messaging apps is most widespread, in particular among extension agents and input dealers, but less so among output dealers. WhatsApp is most common (by 98 percent of all app users) followed by Facebook Messenger (49 percent) and Telegram a distant third (8 percent). Among the social networks used by these two intermediary groups, Facebook clearly dominates (93 percent of social network users) while Twitter and Instagram are only used by around 15 percent of users. Most of the social network members use these platforms daily (89 percent), while 78 percent communicate via text messaging apps on a daily basis. Only extension agents communicate via video calls to any great extent. Most respondents who participate in video calls do so via WhatsApp (94 percent), followed by Zoom (30 percent).

Interesting differences can be observed with regard to mobile payments where prevalence of use does not follow the common pattern of higher usage rates among extension agents and input dealers.

Instead, mobile payments are more widely used among input and output dealers than extension agents. Differences are particularly pronounced when comparing usage rates among intermediaries with the necessary skills. The data shows that a large majority of output and input dealers who have the skill to use mobile money in fact do so (93 and 89 percent). In contrast, the share of extension agents that use mobile payments in their work is lower (65 percent), one of the lowest usage rates among all mobile phone functions. There is a similar pattern in all four countries with broadly comparable usage rates. Averaged across the three groups, the prevalence is slightly higher in Kenya (88 percent) than the other four countries (ranging between 78 and 82 percent).

The share of dealers who use mobile payments in business transaction differs by the type of value chain actors they exchange money with. In the case of output dealers, mobile money use is more frequent when purchasing outputs from other intermediaries (41 percent[3]) and selling them to consumers and other output dealers (both 39 percent) compared to purchase from producers at the farm gate (30 percent). Input dealers most frequently report using mobile money when buying inputs from other dealers (30 percent) and selling them to customers (33 percent).

While the responses show that intermediaries use a wide range of mobile phone functions, clear preference emerge when asked about the two most frequently used functions (Table 6). The use of different functions is still most diverse among extension agents, but voice calls and SMS dominate, followed with some distance by Internet, photo camera and text messaging apps, while the remaining functions are hardly cited despite widespread use. Mobile payments are particularly notable in this regard, which are used by 61 percent of all extension agents, but only cited by 3 percent among the two most frequently used functions. Among dealers, voice calls remain most important followed by mobile payments. Widely used functions such as video calls or video camera are hardly mentioned. Just four intermediaries selected digital agriculture services among the most frequently used mobile phone functions (Twiga Foods in Kenya, Senekela in Mali, and Esoko and Farmerline in Ghana).

4.1.2.4 ICTs and information provision

The majority of intermediaries use ICTs to send and receive information (98 percent extension agents, 81 percent output dealers, 89 percent input dealers). Respondents were asked a series of questions to better understand the flow and content of information shared via ICTs.

In terms of professional contacts, input and output dealers mainly use ICTs for information exchange with producers and fellow dealers (Figure 5). Output dealers share information with the least diverse network. Interestingly, they listed 'friends and family' much more frequently than the other two intermediary groups, suggesting that these play a more important role in their business activities. In addition to producers and other agro-input dealers, extension agents and agro-output dealers are also listed by a certain share. Only a few dealers exchange information with NGOs or government officials.

Extension agents use ICTs to exchange information with the most diverse network, but frequencies and the main direction of information flow differs by type of recipient. The large majority of agents use ICTs to provide information to producers, but just over half also use them to receive information. Many also use ICTs to exchange information with government officials, other extension agents and to a lesser extent NGOs. Information exchange with input dealers is more common than output dealers.

[3] Shares in the remainder of this section as calculated as the share of intermediaries in the respective group who state that they perform this professional activity.

Figure 5: Information flows via ICTs between different types of intermediaries and other actors

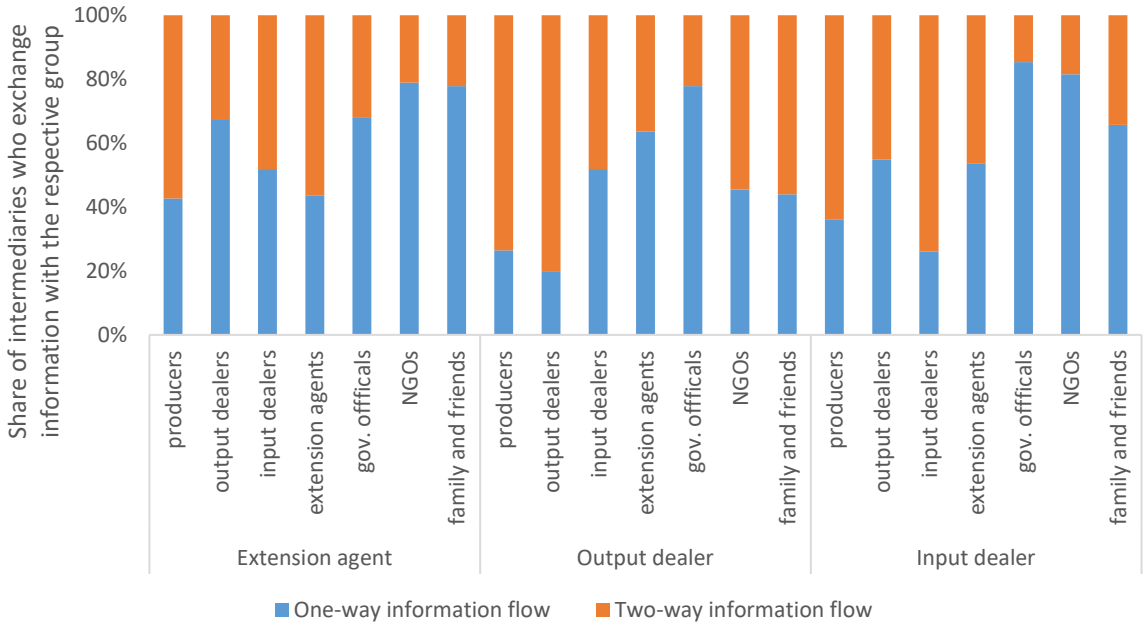
N (extension agents) = 440, N (output dealers) = 500, N (input dealers = 468); shares computed using weights (see Table A1).
Source: Authors' compilation

Many intermediaries use ICTs to both send and receive information from different actors, but for some actors one-way information flows are more common (Figure 6). Thus, just under two-thirds of respondents overall use ICTs for two-way exchange of information with producers and dealers while information from government officials and NGOs mainly flows from these sources to the intermediaries (72 and 77 percent respectively). In particular input and output dealers commonly engage in two-way information exchanges with fellow dealers via ICTs and to a lesser extent with producers. While many extension agents also exchange information with producers and dealers in both directions, larger shares also only send information, notably to output dealers and producers.

Given that information exchanges with producers are common among all intermediary groups, it is worth taking a closer look at the type of information shared via ICTs. By far the main information provided by input and output dealers relate to input and output prices (shared by 90 and 88 percent respectively). Over half of output dealers also offer information about buyers to producers (58 percent), thus facilitating market linkages. Around three quarters of input dealers are a source of information about production methods, technologies and inputs for producers (76 percent). Extension agents share the widest range of information, primarily on production methods (88 percent), but also government programs (49 percent), weather (45 percent), input prices (42 percent) and output prices (36 percent). Information about buyers and sources of finance are least frequently shared via ICTs to producers (both 17 percent).

The responses also show, however, that many intermediaries still prefer to exchange certain type of information face-to-face (Table 7). Thus, among the output dealers that exchange information via ICTs, almost two-thirds would prefer to exchange information about output prices personally, but only a third about buyers. Similarly, just over half of input dealers prefer face-to-face exchange of input prices. Information about production methods and inputs is also preferably exchanged face-to-face, in particular among extension agents, but also input dealers. However, regarding other information commonly shared by extension agents, such as weather and prices, ICTs seem to be a suitable medium and only few agents would prefer face-to-face exchanges.

Figure 6: Two-way and one-way information flows via ICTs



N (extension agents) = 440, N (output dealers) = 500, N (input dealers = 468); shares computed using weights (see Table A1).
Source: Authors' compilation

Table 7: Preference for exchanging information face-to-face rather than via ICTs

	Extension agent	Output dealer	Input dealer
Weather	12	1	8
Output prices	10	60	17
Input prices	16	16	53
Production methods/ technologies/inputs	84	22	54
Buyers	6	33	15
Sources of finance	19	27	20
Government programmes	39	14	14
Other	3	5	2
No information	11	12	8

Share of intermediaries that send / receive information via ICTs; N (extension agents) = 440, N (ouput dealers) = 500, N (input dealers = 468); shares computed using weights (see Table A1).
Source: Authors' compilation

4.1.2.5 Digital agricultural service

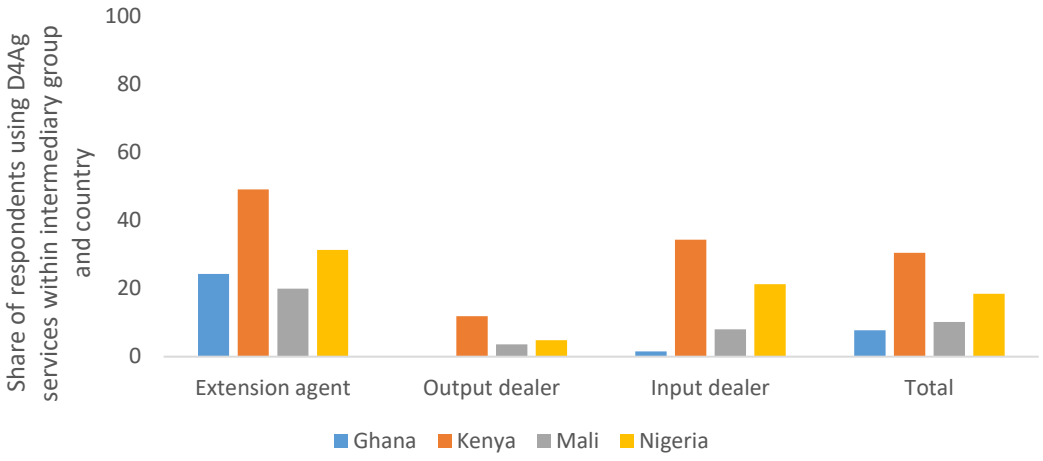
Despite the widespread use of ICTs in professional activities and a high prevalence of smartphones, D4Ag services are only used by a minority of respondents across all intermediary groups. The share of users is higher among extension agents (31 percent) and input dealers (16 percent) while only 5 percent of output dealers use D4Ag services. While only a few non-users (9 percent across all groups) do not have the necessary device to use D4Ag services, most of them state that they do not have the skill to use D4Ag services (80 percent). The largest share of respondents that do not have the necessary device is found among output dealers (15 percent of non-users) while skill levels are comparable between non-users in the three intermediary groups.

D4Ag users more frequently use a smartphone as their main ICT than intermediaries in the entire group. Thus, 92 percent of extension agents who use a digital agriculture service use a smartphone as their main ICT compared to 87 percent of all agents. Similarly, 69 percent of output dealers and 76 percent of input dealers who use a digital agriculture service use a smartphone compared to 53 percent and 68 percent respectively across their entire group. These findings may suggest that smartphone use facilitates D4Ag uptake. However, D4Ag use and smartphone adoption may also be influenced by a confounding factor, i.e. the kinds of intermediaries that use smartphones may also be the kinds of intermediaries that use a D4Ag service e.g. due to a higher level of education.

It is interesting to note that while usage of D4Ag services is generally low, a large share of respondents across all intermediary groups do use them if they are able to do so. The difference is most striking among output dealers where only 5 percent of all respondents use D4Ag services, but 55 percent of those with the necessary skill and device do so. Similarly, 72 percent of extension agents and 65 percent of input dealers with the required skills and device use these services, compared to 31 percent and 16 percent respectively as a share of the entire intermediary group. While it is not clear whether the skill to use D4Ag service result from or are enabling their use, the two impact pathways are likely to be reinforcing.

Differences in usages rates can be observed across the four countries (Figure 7). The highest share of D4Ag users are found in Kenya (31 percent of Kenyan respondents) followed by Nigeria (18 percent) while only a few respondents make use of such services in Mali and Ghana (10 and 8 percent respectively). In particular among Kenyan extension agents, usage of D4Ag services is noticeably higher than in the other countries (49 percent). Other intermediary groups that stand out because of relatively high usage rates are extension agents in Nigeria (31 percent) and input dealers in Kenya (34 percent).

Figure 7: Use of digital agriculture services by intermediary group and country



N = see Table 2; shares computed using weights (see Table A1).
Source: Authors' compilation

The services used are most diverse in Kenya (24 different types of services), followed by Ghana (8), Mali (6) and only 2 in Nigeria. Among D4Ag services used, none stands out. Most frequently used are Esoko in Ghana, Digifarm and iCow in Kenya, Senekela in Mali and Agromall and Farmcrowdy in Nigeria, but the numbers of actual users per service is low, ranging between 15 and 34 respondents. Digifarm, Senekela and Farmcrowdy are used by all intermediary types (although still only very few output dealers). The remaining services are mainly used by extension agents.

4.1.2.6 Change in ICT use over time

Most intermediaries (62 percent) reported an increase in ICT use in their professional activities in the five years prior to the Covid-19 pandemic, with around 37 percent reporting that it had increased a lot and 25 percent that it had increased a little. The shares are comparable across the intermediary groups. On average 21 percent did not see any change; this share was highest among input dealers (24 percent) and lowest among output dealers (12 percent). Only 13 percent on average felt that use had decreased, but mostly only a little.

According to the respondents who said that the frequency of using their main ICT had increased, the most frequently cited reasons include improvements in network connectivity, better access to ICTs among clients, and changes in the nature of professional activities (Table 8). Other reasons include greater awareness of the utility of ICTs, improved skills to use ICTs and cheaper devices. Other possible reasons, such as improved functions of the devices, reduced costs of usage, better access to electricity and increased trust in ICTs, played a less significant role.

Table 8: Reasons for increased usage of ICTs in professional activity

	Extension agent	Output dealer	Input dealer	Total
Network connectivity has improved	41	53	42	44
My clients/customers have better access to ICTs	29	42	42	37
I have become more aware of the usefulness of ICTs for my professional activities	35	32	29	31
The nature of my professional activities has changed which made use of ICT	32	23	24	26
My skills to use ICTs have improved , ICTs have been become easier to use	27	26	22	24
Devices have become cheaper	17	26	19	20
Devices offer more functions than before	19	19	17	18
Useful apps/digital services have become available	22	8	15	15
Access to electricity has improved	12	13	15	13
Using the devices (e.g. cost of SMS, data etc.) has become cheaper	14	9	14	12
I have more trust in ICTs	8	9	6	7
Other reasons	2	3	2	2

Share of respondents who stated that the use of the main ICT had increased in the five years prior to the Covid-19 pandemic; N (extension agent) = 312, N (output dealer) = 373, N (input dealer) = 332.
Shares computed using weights (see Table A1)
Source: Authors' compilation

Increasing use of ICTs has led to a reduction in face-to-face contact. Around two-thirds of intermediaries felt that the frequency of face-to-face interactions had decreased as a result of using ICTs (63 percent), mostly a little (41 percent). A decrease was reported in particular by extension agents (68 percent) and input dealers (63 percent). Among output dealers, who make less use of ICTs than the other two groups overall, 57 percent reported a decrease in face-to-face contact. Only 12 percent of intermediaries said that such interactions had increased. The correlation analysis results also indicate significant relationship between increase in ICT usage and decrease in face-to-face interaction (-.083 at the 0.01 level).

4.1.2.7 Constraints to using ICTs

Costs and lack of usefulness emerged as the main constraints to using different ICTs (Table 9). In the case of tablets, smartphones and computers, the cost of the device, rather than the cost of using the device, was cited by the largest share of respondents. In the case of radio, TV and feature phone[4], lack of usefulness for their professional activities was most frequently mentioned, but a smaller share felt the same with regard to computers, tablets and smartphones. Skill constraints were noted in particular for computer, tablet, feature and smartphone, but less commonly than other reasons. Poor connectivity and electricity access rarely featured among the concerns, as did lack of trust (by respondents or clients) or lack of access to the ICT among clients. These trends were broadly similar across all intermediary groups. Among output dealers, lack of usefulness was more frequently cited as a constraint than cost while for extension agents and input dealers, it was the other way round.

Table 9: Most frequently cited constraints to using different ICTs in professional activities

		Extension agents		Output dealers		Input dealers	
		Share	*N*	*Share*	*N*	*Share*	*N*
Computer	Too expensive to purchase	37	236	30	546	45	424
	Not useful/necessary for my professional activities	23		36		23	
	I don't know how to use it	4		20		13	
Feature phone*	Not useful/necessary for my professional activities	43	14	57	90	42	57
	Too expensive to purchase	29		22		33	
	I don't know how to use it	7		11		11	
Radio	Not useful/necessary for my professional activities	64	373	75	532	69	456
	Poor network connectivity	12		8		10	
	Too expensive to purchase	8		9		10	
Smartphone*	Too expensive to purchase	50	28	43	244	51	128
	Not useful/necessary for my professional activities	7		23		16	
	I don't know how to use it	4		17		14	
Tablet	Too expensive to purchase	49	373	38	573	45	496
	Not useful/necessary for my professional activities	24		37		28	
	I don't know how to use it	3		14		9	
TV	Not useful/necessary for my professional activities	58	411	69	547	64	489
	Too expensive to purchase	16		14		20	
	Lack of electricity	8		5		9	

The table shows the top 3 most frequently cited constraints. Other options not included here were: "too expensive to use", "my clients/business partners don't have access", "my clients/business partners do not trust it", "I don't trust it" and "other".
* Respondents were only asked about constraints to using more sophisticated phones than the phone they had listed as their main ICT.
Shares computed using weights (see Table A1).
Source: Authors' compilation

[4] Most of the respondents who did not regard feature phones as useful used a basic phone.

4.2 Impact of ICT use among intermediaries

4.2.1 Ability to provide professional services

Extension workers were asked whether they felt that ICTs had helped them to better assist producers at the production and at the marketing stages. Dealers were asked whether ICTs had improved their ability to interact with producers, input suppliers (input dealers) or buyers (output dealers), and whether ICTs had improved their ability to run their business. The large majority of intermediaries said that ICTs had brought benefits in all of these areas. Several main impact pathways become apparent when examining the more detailed responses.

Among extension agents, more respondents felt that they were able to better assist producers at the production (99 percent) than marketing (90 percent) stage. At the production stage, ICTs mainly helped them to provide information about crop/livestock production methods (79 percent of those that were better able to assist at production stage) and weather updates (29 percent). Many also felt that ICTs made it easier to obtain timely information about on farm operations from producers (42 percent) and to understand producers' problems (29 percent), underlining the importance of two-way communication between extension agents and producers.

At the marketing stage, the largest share of extension agents reported that they were able to provide producers with better access to information about commodity prices (60 percent of those that were better able to assist at marketing stage) via ICTs. Around half also noted that ICTs had helped to reduce travel time (49 percent) and a third shared information about buyers (35 percent). Fewer extension agents reported benefits related to the actual marketing activities, however, such as better linkages to buyers (23 percent), collective bargaining (15 percent), reduced post-harvest losses (14 percent) or timely output sales (10 percent).

Among output dealers who feel that ICTs have improved their ability to interact with producers and buyers (67 percent), better access to information about producers (46 percent) and buyers (47 percent) ranked among the main benefits of ICTs. Almost half of them also felt that interactions with buyers had become easier (46 percent), but less so with producers (38 percent). Similarly, more output dealers reported that ICTs had increased the number of buyers (34 percent) they interacted with than the number of producers (18 percent). These differences could be due to differential access to ICTs among the producers and buyers. Efficiency gains were also reported by many output dealers through reduced travel times (36 percent).

The large majority (96 percent) of output dealers also noted that ICTs had helped them run their business. Better access to information again ranked highest. Specifically, 70 percent of output dealers who reported improvements in running their business said that ICTs had improved access to commodity prices. ICTs also helped with business transactions, including better timing of output purchases or sales (54 percent) and faster payments from customers (57 percent). However, these benefits do not seem to have translated into higher profits for most output dealers which was only mentioned among the benefits by 23 percent of dealers. ICT use also did not noticeably improve access to credit and only 9 percent said that it had helped them with book-keeping.

Among the input dealers who reported that ICTs had improved the ability to interact with input suppliers and customers (97 percent), better access to information also featured most prominently among the impact pathways. In particular access to information about different types of inputs (72 percent), but also how to apply inputs (43 percent) and where to source them (32 percent) had improved, but less so information about customers (15 percent). Around a quarter also felt that interactions with customers and suppliers had become easier. Twenty-one percent of input dealers reported reduced travel times. Trading patterns do not seem to have been significantly affected by ICT use, however, including linkages to more suppliers (10 percent) and customers (15 percent).

Most input dealers felt that ICTs had improved their ability to run their business (96 percent). The specific benefits mirror those cited by output dealers. The most frequently cited benefit was better access to information about input prices (77 percent), followed by better timing of input purchases / sales (50 percent) and faster payments from customers (62 percent). Similar to output dealers, only 20 percent of input dealers reported higher profits as a result of using ICTs and access to credit had not improved. A slightly larger (but still low) share than output dealers used ICTs for book-keeping (12 percent).

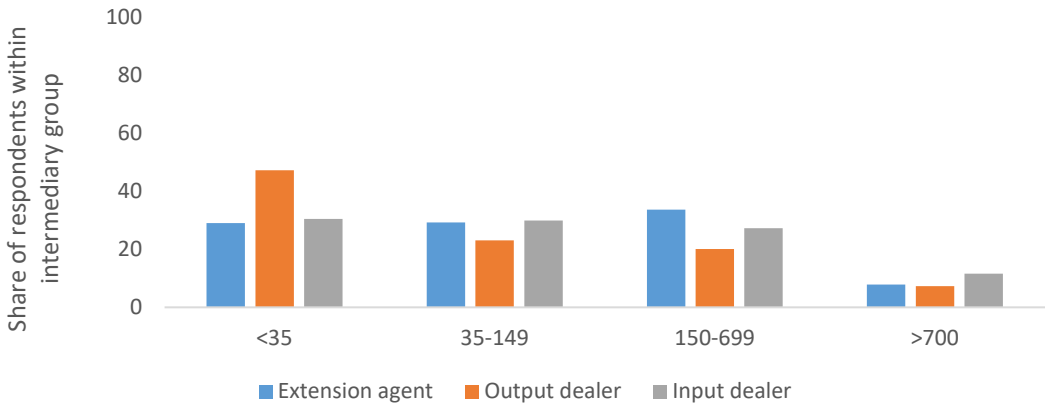
The few respondents (104) who stated that ICTs has made implementation of their professional activities more difficult were asked to elaborate on these issues. The largest share complained that ICT use has increased expenses due to the high cost of purchasing and/or using ICTs (24 percent of those who reported difficulties, especially among input dealers). Several also noted that they had received false information through ICTs (12 percent, especially among dealers). Difficulties mentioned by only a few respondents (3-4 percent) included the risk that information does not remain confidential, health risks and increases in produce prices as a result of using ICTs. One respondent also felt that ICT use made one lazy. The remaining most frequently cited problems referred more generally to constraints to using ICTs, including lack of skills to use the technology (32 percent, in particular among output dealers) and a preference for face-to-face interaction (18 percent, in particular among extension agents)

4.2.2 Networking and collective action

4.2.2.1 Networking with value chain actors

Survey participants were first asked a series of questions about the linkages between mobile phone use and interactions with agricultural producers. Overall, extension workers interact with the largest numbers of producers, but network sizes of individual extension workers differs widely (Figure 8). The same is true for input dealers who on average interact with fewer producers than extension agents. Output dealers have the smallest network and almost half of them communicate with less than 35 producers.

Figure 8: Number of producers interacted with before the Covid-19 pandemic



Question: How many producers did you interact with in a busy month before the Covid-19 pandemic?
N = see Table 2; shares computed using weights (see Table A1)
Source: Authors' compilation

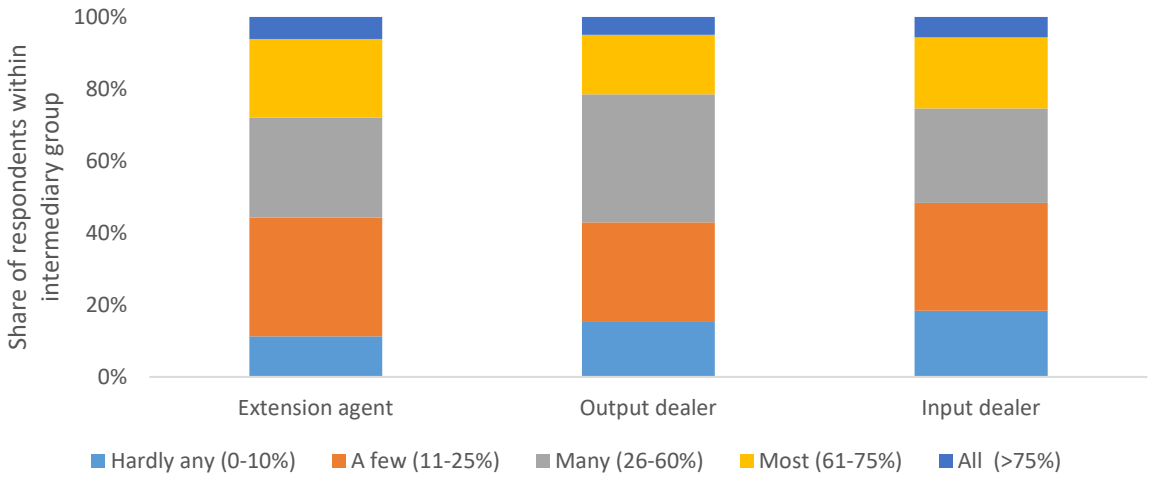
The share of producers that intermediaries communicate with using their mobile phones differs across respondents and trends are not very clear. On average, 30 percent communicate with "a few" and the same share with "many" producers using their phone (Figure 9). Extension agents most frequently state that they communicate with most of the producers they interact with. Very few communicate

with all of their producers. Overall, the data show that in all three groups there is still a sizeable share of producers that are not reached via mobile phones.

Relating the number of producers contacted with the share of interactions via mobile phones could give an indication of whether network size might influence intensity of mobile phone use to contact network members. The correlation analysis points to a significant positive correlation, i.e. the larger the network, the larger the share of members contacted vial mobile phones (.056 at the 0.05 level).

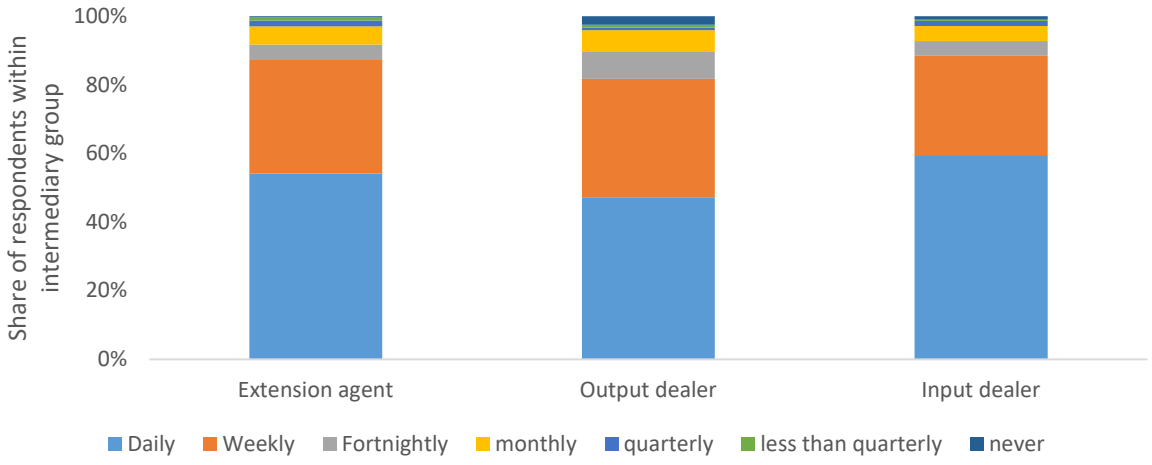
Where intermediaries do use their mobile phone for communicating with producers, they do so frequently. Most of the respondents communicate on a daily basis (in particular input dealers and extension agents) or weekly (Figure 10). The frequency is lowest among output dealers, but nevertheless high with 80 percent interacting daily or weekly via the mobile phone. The correlation analysis shows a negative correlation between share of producers and frequency of interaction (-.215 at the 0.01 level), i.e. the larger the share of producers communicated with via mobile phones, the less frequent the interactions with them via mobiles.

Figure 9: Share of producers contacted by via mobile phone



Question: Please indicate the share of producers who you interacted with using your mobile phone in a busy month before the Covid-19 pandemic.
N = see Table 2; shares computed using weights (see Table A1). Source: Authors' compilation

Figure 10: Frequency of interacting with producers via mobile phone



Question: How frequently did you interact with producers using your mobile phone before the Covid-19 pandemic?
N = see Table 2; shares computed using weights (see Table A1). Source: Authors' compilation

The data also show that use of mobile phones has increased networks with producers, but not universally so. Almost half of all respondents (46 percent) felt that using the mobile phone had increased the number of producers they interact with in the five years prior to the Covid-19 pandemic, in particular among extension agents and less among input dealers and output dealers (Table 10). At the same time, a sizeable share of respondents also noted that the number had not changed (38 percent) or even decreased (16 percent), in particular among input and output dealers. Given the rapid spread of mobile phones in the past 15 years, this seems less dynamic than might be expected.

Table 10: Changes in number and frequency of interactions related to mobile phones

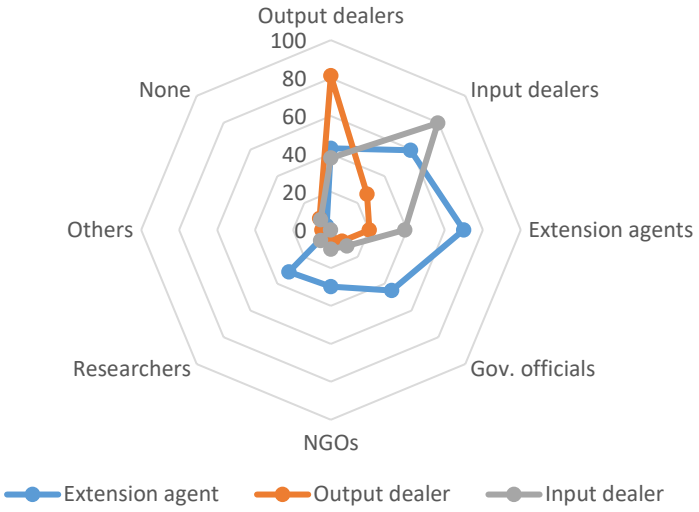
		Extension agents	Output dealers	Input dealers
Change in the **number** of producers interacted with as a result of mobile phone	Decreased a lot	4	7	7
	decrease a little	9	11	12
	no change	31	41	40
	Increased a little	31	27	23
	Increased a lot	25	15	19
Change in **frequency of interactions** with producers as a result of using mobile phones	Decreased a lot	5	7	7
	decrease a little	13	13	12
	no change	26	38	38
	Increased a little	33	27	26
	Increased a lot	23	16	18

Change in the 5 years prior to the Covid-19 pandemic
Share of respondents within intermediary group (N = see Table 2); shares computed using weights (see Table A1).
Source: Authors' compilation

Respondents were also asked whether mobile phone use had increased the frequency of interactions with producers. The responses mirror those related to the changes in number of producers interacted with. Almost half of the respondents reported a higher frequency while around a third saw no change and the remaining 19 percent a decrease. Changes in number and frequency are correlated (.578 at the 0.01 level). Thus, mobile phones seem to have increased network size and interaction frequency simultaneously, but decreased them simultaneously as well. Around two thirds of respondents (64 percent) felt that the use of the mobile phone had decreased face-to-face interactions with producers.

A large majority of intermediaries (93 percent) also use their mobile phone to interact with other value chain actors in addition to producers. Within each intermediary group, respondents most often list members from their own group. This is most pronounced among output and input dealers where around 81 and 80 percent respectively use mobile phones to interact with their peers. Close to 40 percent of input dealers also use mobile phones to get in touch with output dealers and extension agents, while only around a quarter of output dealers do so with regard to extension agents and input dealers. While extension agents also most frequently listed their colleagues (70 percent), they have the most diverse mobile phone-enabled networks that also includes output and input dealers, government officials, NGOs and researchers.

Figure 11: Interactions with other value chain actors via mobile phones



Question: In addition to producers, which other value chain actors do you interact with using your mobile phone? Share of respondents within intermediary group (N = see Table 2); shares computed using weights (see Table A1). Source: Authors' compilation

4.2.2.2 Group activities

Twenty-seven percent of intermediaries belong to a group that uses ICTs to coordinate the group or implement group activities.[5] Extension agents (36 percent) and input dealers (27 percent) are more frequently part of such groups than output dealers (18 percent). Most groups are formally registered (75 percent), but in particular extension agents also participate in ICT-enabled informal groups. Most input and output dealers belong to a group with just one type of member, usually their fellow intermediaries. Groups with more than one member type mostly also include producers. Extension agents have more diverse group networks. Only 22 percent are members of groups that include only extension agents. The rest either joined groups with one other type of member or with multiple members, incl. government officials, extension agents and producers. The main purpose of these groups are related to the core activities of the intermediaries, i.e. linking producers and input or output dealers (most frequently cited by dealers) and information dissemination (most frequently cited by extension agents, but also by dealers).

While all of these groups use ICTs, in-person meetings appear the preferred communication channel (Table 11). Thus, in-person group meeting were the most frequently cited means of communication across all intermediary groups while around a third of respondents who are part of ICT-enabled groups also communicated through bilateral meetings. Phone calls also featured highly, listed by 71 percent of respondents. Extension agents more often mentioned other mobile phone functions, such as SMS or text messaging apps, but less frequently than phone calls. Comparing groups that include producers with those that do not shows that in-person meetings are most frequently cited for interactions in groups with producers, but phone calls are almost equally often mentioned as for groups without producers (Table 11). Text messaging apps, in contrast, are more often used to communicate in groups that do not include producers.

[5] Percentages in this section refer to the share of respondents (total or within intermediary group) who are members of ICT-enabled groups.

Table 11: Main channels of communication for ICT-enabled groups

	All groups	Groups with producers	Groups without producers
	N=448	*N=205*	*N=243*
In-person bilateral meetings	39	53	25
In-person group meetings	76	83	69
Phone Calls	71	73	70
SMS	23	22	25
Email	5	3	6
Video Call apps	1	0	0
Text messaging app	13	5	20
Social Networking Platform	5	3	6
Digital agriculture service	0	0	0
Other apps	0	0	0
Other	0	0	0

Question: Prior to Covid-19 what were the main channels of communication for the group? (up to 3)
Share of intermediaries who are part of an ICT-enabled group
Shares computed using weights (see Table A1)
Source: Authors' compilation

Intermediaries see the main benefit of using ICTs in group activities in speeding up communication which was cited by 85 percent of respondents, in particular among input dealers. Other benefits cited by all intermediaries, but in particular extension agents, include reduced cost of communication (31 percent of all), improved access to information for group members (21 percent), improved information exchange within the group (18 percent). Output dealers also value ICTs for facilitating procurement of output from producers (27 percent of output dealers) while several input dealers mentioned greater ease of payments for inputs (22 percent of input dealers).

Potential benefits that were not commonly selected (i.e. by less than 20 percent) provide interesting insights on the limitations of ICTs to facilitate group activities. Thus, ICTs do not seem to play a significant role in facilitating collective action by the group. Specifically, ICTs were not seen to improve the groups' capacity to facilitate access to or reduce the cost of credit, insurance or machinery, empower women and the youth, voice concerns in political processes or improve access to inputs for producers. ICTs were also not widely perceived to aid in the development and adaptation of innovations by the group. While a small share of extension agents felt that ICTs increased the quality of training offered by the group (8 percent of extension agents), hardly any said that they had increased the frequency or reach of training. In terms of income effects, 11 percent of intermediaries (esp. extension agents) felt that producer incomes had increased as a result of using ICTs in the group, while only 5 percent of input dealers thought that their revenue had increased.

A small share of respondents (10 percent) also stated that ICTs have made the implementation of group activities more difficult. While this small sample may not be representative, it nevertheless gives some interesting hints that could be explored in future research. The main concerns related to the inclusiveness of ICTs. Three-quarters of those who reported difficulties felt that ICTs limited participation of some group members while half of them thought that ICTs had led to differential access to information among group members. Close to a third (in particular output dealers) also said that ICTs had slowed decision-making.

4.3 Influence of the Covid-19 pandemic

For a large number of intermediaries, use of ICTs in professional activities increased during the Covid-19 pandemic, but less than may be expected given (temporary) restrictions on personal interactions, movement and business operations implemented in these countries (Hale et al., 2020). Increases in usage were reported in particular by extension agents (76 percent) who already made more extensive use of ICTs before the pandemic (Table 12). Just over half of the dealers reported an increase in their ICT use as well, but the rest did not see a change and a few even a decrease.

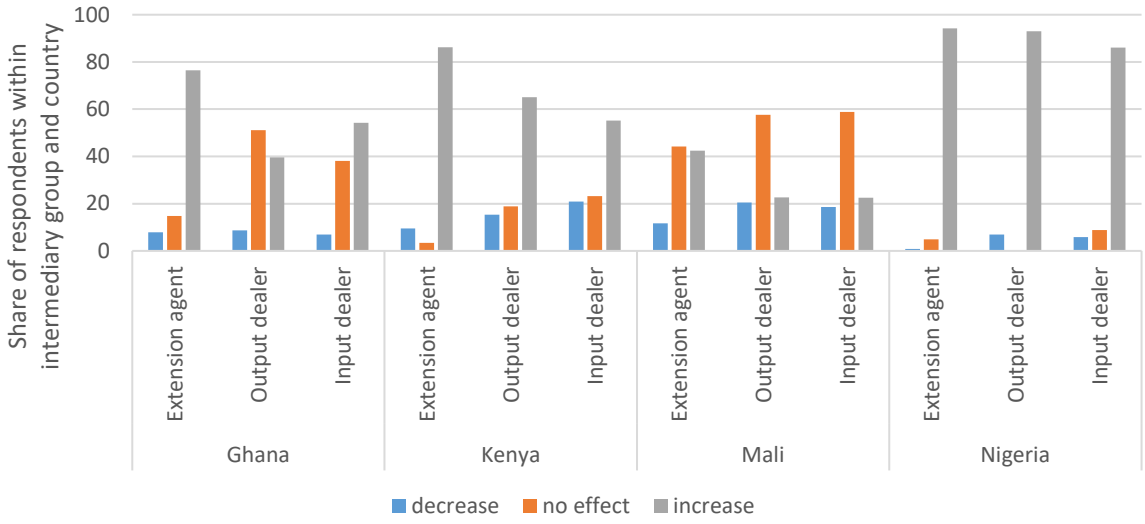
Table 12: Changes in the frequency of using ICTs for professional activities during the Covid-19 pandemic

	Extension agent	Output dealer	Input dealer
Decreased a lot	2	7	5
decreased a little	6	7	10
no effect	21	38	36
increased a little	28	23	22
increased a lot	43	25	27

Question: How has the Covid-19 pandemic affected the frequency of using [main ICT] for professional activities?
Share of respondents within intermediary group (N = see Table 2)
Shares computed using weights (see Table A1). Source: Authors' compilation

Large difference emerge, however, when comparing responses between countries (Figure 12). By far the largest share of intermediaries in Nigeria said that they were using ICTs more frequently during the Covid-19 pandemic (91 percent), in particular among extension agents and output dealers. In Kenya, increase in use was more pronounced among extension agents (86 percent), but also reported by the majority of dealers. While use also increased among the majority of extension agents in Ghana (77 percent), a large share of dealers (and in the case of output dealers the majority) felt that the pandemic had had no effect on ICT use. Responses by intermediaries in Mali show noticeable differences, however, where the majority in all groups did not report an effect (54 percent, especially among dealers). The largest (although comparatively small) shares of intermediaries who had decreased the use of ICTs is found among dealers in Kenya (16 percent) and Mali (17 percent).

Figure 12: Changes in the frequency of using ICTs for professional activities during the Covid-19 pandemic by country

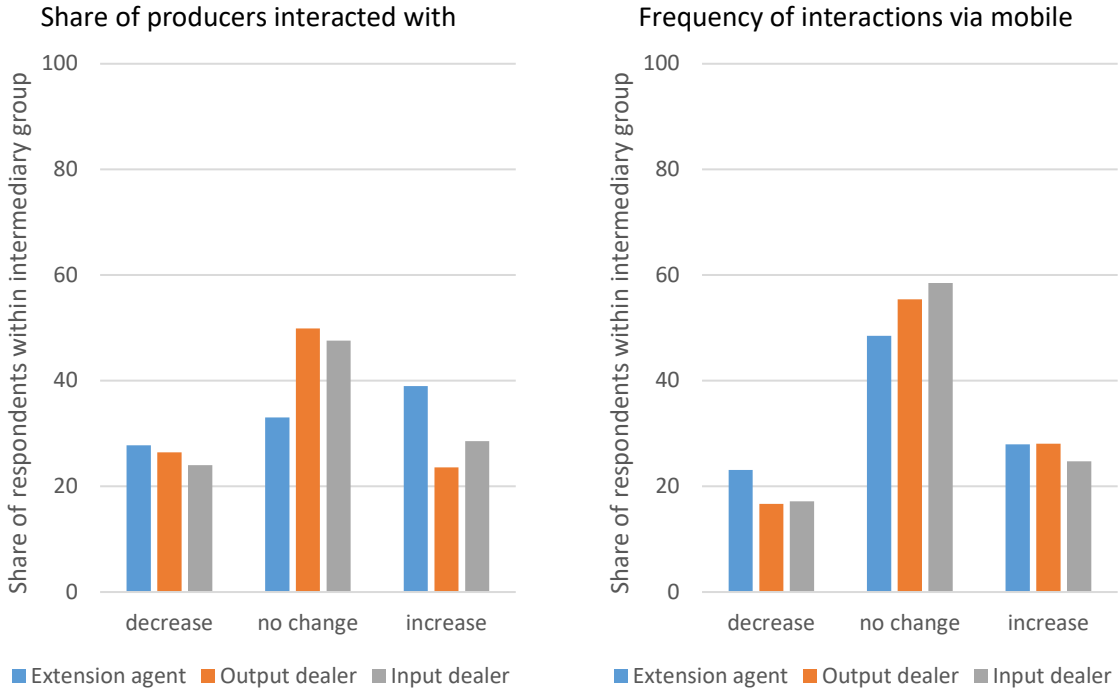


N = see Table 2; shares computed using weights (see Table A1). Source: Authors' compilation

The pandemic does not seem to have substantially increased the share of producers that intermediaries interact with via their mobile phone (Figure 13). Around half of the output and input dealers continued to communicate with the same share of producers via their mobile phone while 24 percent of output dealers and 29 percent of input dealers reported an increase. Changes are a little more pronounced among extension agents were 39 percent increased the share of producers they interact with via mobiles. The pattern of changes are similar across the intermediary groups. Among those that report changes, most had increased from 'a few' to 'many' and 'a few' or 'many' or to 'most'. Decreases were mainly from 'many' to 'a few' and 'most' to 'many'.

Even fewer changes are apparent with regard to the frequency of interaction with producers via mobile phones (Figure 13). Less than 30 percent of respondents within the different intermediary groups reported an increase in frequency of interactions, while the majority did not report a change. Where interactions changed, they mainly increased from daily to weekly or vice versa.

Figure 13: Changes in interactions with producers via mobile phones during the Covid-19 pandemic



N = see Table 2; shares computed using weights (see Table A1).
Source: Authors' compilation

5 Discussion

This study assesses the use and perceived impact of ICTs among agricultural intermediaries in Ghana, Kenya, Mali and Nigeria. The results show that intermediaries make extensive use of ICTs in their professional activities, much more so than a decade ago (Okello, 2011). All of the intermediaries use some kind of ICT. Mobile phones clearly dominate among the digital technologies, most commonly smartphones, which are often used daily. While voice calls are still the preferred communication channel, other channels are gaining in importance, notably SMS, voice messaging apps and social networking platforms. According to the surveyed intermediaries, expansion in ICT use was driven mainly by improvements in network connectivity and better access to ICTs among clients. Higher-tech devices (such as more sophisticated phones, computers or laptops) are often seen as too expensive while traditional ICTs (such as TV and radio) are mostly not regarded as useful.

The findings confirm that D4Ag services are not yet widely used in African agriculture. For the most part, D4Ag service adoption is higher in countries where such services are more prevalent, with the exception of Ghana where the share of respondents using such services are low even though availability is comparable to Nigeria (Table 1). Contrary to the findings of Kieti et al. (2022), the results suggest that skill gaps may be a more important constraint to D4Ag use than lack of access to the necessary devices or poor connectivity (technology infrastructure) or the high costs of mobile phones (service affordability, excluding the cost of D4Ag use which was not assessed).[6] This difference could be explained by the fact that the majority of respondents surveyed by Kieti et al. (2022) were involved in agricultural production while this study focuses on intermediaries, highlighting the importance of well-targeted measures adapted to different user groups to stimulate the uptake of D4Ag solutions.

A recurring pattern emerges with regard to skills, technological capacities and ICT use among the three intermediary groups which can inform D4Ag service design. The pattern can be seen with regard to levels of education in general as well as the level of digital skills, both of which are highest among extension agents, followed by input and then output dealers. Similarly, extension agents use ICTs in the widest range of activities with the most sophisticated digital technologies and most diverse mobile phone functions, including the highest prevalence of D4Ag services use. They also interact with the most diverse network of value chain actors and share the widest range of information via ICTs. A notable exception to this trend are mobile payments which are more widely used among input and output dealers.

A broad comparison between the four countries shows some expected, but also some unexpected patterns. Digitalization among intermediaries (e.g. in terms of digital skills, sophistication of devices and diversity of functions used, D4Ag uptake etc.) is more advanced in Kenya, as could be expected given the frontrunner position of the country in terms of D4Ag service development in Africa. Also as expected, Nigerian intermediaries ranked somewhere in the middle. Digitalization among intermediaries in Ghana seems surprisingly low, however, given the country's good performance in various ICT-related indicators and the highest score in the Agriculture Digitalization Index among the four countries (Table 1). The discrepancy may partially be explained by the relatively high share of women among Ghanaian output dealers surveyed who have less access to higher tech phones than their male colleagues. In contrast, digitalization among intermediaries in Mali is more advanced than would be expected, in particular in terms of smartphone use, given the supposedly poor performance of the country in these indicators. The comparable usage rates for mobile payment services across countries is also notable, given that the countries differ substantially with regard to the prevalence of

[6] This study did not assess to what extent discoverability or usability (Kieti et al., 2022) may impede the uptake of D4Ag solutions. The higher adoption rates in Kenya where D4Ag solutions are more prevalent than in the other four countries suggests that discoverability may also play a role among intermediaries.

mobile money.[7] These findings suggest that self-motivation could be a key driver in adoption, i.e. where users perceive a utility in the digital tools, they will take advantage of them even if the context is not entirely conducive.

Three areas of impact can be identified. First, ICTs facilitate information sharing between intermediaries and other value chain actors. Indeed, this was found to be the main activity and benefit across the three groups. Information is obtained and shared primarily through direct bilateral and group communication, but less so obtained from the Internet. Looking at the types of information exchanged, the intermediary groups are differently suitable to disseminate different kinds of information. Extension agents can play a particularly important role here, given the diversity of professional activities, networks and information shared. Interestingly, while dealers commonly use ICTs to exchange information about prices, they in fact prefer to do so face-to-face, possibly to strengthen their bargaining position. Thus, extension agents may be more suitable disseminators of price information. At the same time, input dealers are found to use ICTs frequently to obtain and provide information about types and application of inputs, thus complementing the role of extension agents as an important source of such information for producers. In both cases, however, the intermediaries prefer to provide such information, which may require demonstrations or explanations, in-person rather than via ICTs.

Second, ICTs facilitate networking among value chain actors. The technologies seem particularly useful to facilitate communication with larger networks, i.e. the larger the network, the larger the share of actors contacted via mobile phone. In the case of dealers, these networks are mainly used for two-way business transactions with producers, other dealers and input buyers. Extension agents interact with a wider range of actors via ICTs and could therefore function as an important bridge. This is apparent in the make-up of the network that they interact and share information with, which more often includes producers, dealers, other extension agents and government officials. They are also part of the most diverse ICT-enabled groups. In addition, ICTs are supporting networking with producers as their main constituency. Digital technologies have helped extension agents to increase the number and frequency of interactions, and the agents interact with producers more commonly via ICTs than dealers, often in both directions. However, for now, ICTs are mainly used for information sharing and less to facilitate market linkages.

The results seem to confirm previous findings that ICTs mainly help to facilitate existing rather than creating new relationships, in particular with regard to market transactions (Boadi et al., 2007; Molony, 2008; Overå, 2006). Output dealers more frequently value ICTs for making interactions easier rather than for increasing them. Similarly, input dealers feel that ICTs have made interactions with suppliers and customers easier, but only few report better linkages. Many dealers also say that the number of producers they interact with and the frequency of interactions did not change as a result of using ICTs. Insights from the Covid-19 pandemic point in a similar direction (see below).

Third, ICTs reduce transaction costs, in particular for input and output dealers. These reductions mainly result from better access to information about buyers, sellers and prices, better timing of produce / input purchases, faster payments from customers and (especially for output dealers) reduced travel times. While ICTs have also improved market linkages to some extent, this impact seems less important. Specifically, dealers use ICTs mainly to connect with fellow dealers and producers / customers, but better linkages seem to be more common with actors up the value chain rather than with producers and more so for output dealers. The priorities differ somewhat between the two types of dealers. While output dealers see the main benefits in easier interactions with buyers and to a lesser extent producers, input dealers value ICTs in particular for facilitating access to

[7] As measured by the GSMA Mobile Money Prevalence Index which ranked Kenya as 'very high', Ghana and Mali as 'high' and Nigeria as 'medium' in 2021. The Mobile Money Prevalence Index is a composite index that considers mobile money adoption, activity and accessibility at country level (https://www.gsma.com/mobilemoneymetrics/#prevalence-index).

information about types, application and sources of inputs. Interestingly, many dealers did not perceive these cost reductions to have translated into higher profits.

In general, verbal and in-person communication remains important in intermediaries' professional activities. Even though the digital channels have become more diverse than what was found by Okello (2011), verbal communication via voice calls is still most common. As noted above, all intermediaries prefer to exchange certain types of information face-to-face. ICT-enabled group members also tend to prefer in-person meetings and some have voiced concerns that ICT use may exclude some members in the group. They do value voice calls as complementary channels, however, in particular to speed up communication. The results also show that producers are still less easily reached via ICTs. A large share of producers is not contacted via mobile phones, including by extension agents who communicate most commonly with producers via ICTs. Output dealers also see less benefit in ICTs to facilitate communication with producers than with produce buyers.

During the Covid-19 pandemic, extension agents seem to have benefited in particular from the increased use of ICTs to interact with their constituency, including with producers they had not interacted with via their mobile phone before. However, only around half of the dealers increased ICT use and some even reported decreases, perhaps due to a slow-down in business activities as a result of Covid-19 containment measures. Somewhat puzzling, ICT use seems to have increased especially in Nigeria as a result of the Covid-19 pandemic. This result could be explained by the fact that the Nigerian government relaxed its containment measures later than Ghana and Mali[8] which may have extended the need for digital communication channels. While the stringency of containment measures in Kenya followed a similar pattern as in Nigeria, the survey shows that before the pandemic ICT use in professional activities was already more common in Kenya than in Nigeria so that existing digital channels could have been used instead.

[8] The stringency of Covid-19 containment measures in the four countries was compared using the Oxford Covid-19 Government Response Tracker (Hale et al., 2021). See Figure A1 in the Appendix for an overview.

6 Conclusion

The results show that with regard to agricultural intermediaries the digital transformation of African agriculture is progressing fast, but it is not (yet) driven by D4Ag solutions. However, widespread adoption of mobile payments among the less digitally advanced output dealers shows that intermediaries are willing and able to make use of mobile phone-enabled services other than communication if they are easy to use, adapted to a wide range of devices, useful for their work and sufficiently widely adopted to create network effects.

Given the widespread use of ICTs among agricultural intermediaries, D4Ag service providers can capitalize on intermediaries‘ existing digital skills, technological capacities and digitally enabled networks to expand their reach, in particular to producers who are still not universally accessible via ICTs, but also to other value chain actors. Intermediaries can also help to maintain personal relationships and direct communication which remains an important component of interactions between actors within and beyond the value chain. In particular extension agents can function as an important bridge facilitated by ICTs and in-person interactions.

In terms of D4Ag services that are likely to be of interest to intermediaries, providers can facilitate existing ICT-enabled activities, in particular the sharing of information with individuals and groups. At the same time, digital services could also support activities where ICTs are currently less widely used, notably facilitating business management and market linkages. In particular with the regard to marketing, providers may be able to overcome challenges faced by virtual markets related to trust, preferences for face-to-face contact and ICT access among producers if intermediaries are built into the design of such services. To this end, further investments in skill development will be required, with targeted training adapted to the skills and needs of the different intermediary groups.

The study is subject to a number of limitations that point to areas for further research. The survey investigated the use and impact of ICTs at the individual level, taking the current context as given. It did not consider how the introduction and use of ICTs may have changed the types of intermediaries involved or the nature of their activities. Additional research could look at such dynamic effects. Moreover, this article provides a descriptive overview of the use and impact of ICTs among agricultural intermediaries. Additional research could statistically explore the driving factors of ICT use and impact.

When assessing impacts, the study relied on the perceptions of the surveyed intermediaries. Further research could quantify the impacts of ICT use among intermediaries on profitability of business operations and the distributional effects of possible income gains. Related findings could inform the design of safeguards in D4Ag services to avoid possible exploitation of small-scale producers or small businesses by intermediaries. Finally, due to the structure of the sample, the study only offers limited insights on gender-related differences between intermediaries. Further research should investigate gender-related dimensions of ICT use and impact among intermediaries, using stratified sampling to ensure a wider representation of women among the respondents. In particular the question whether ICT use empowers or prevents female intermediaries from engaging in related professional activities warrants further attention.

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8 Appendix

Table A1: Weights applied to the sample

Country	Intermediary group	Sample	Target	Weighting factor	Weighted sample
Ghana	Extension agent	82	118	1.4	115
Kenya	Extension agent	89	118	1.3	116
Mali	Extension agent	171	118	0.7	120
Nigeria	Extension agent	121	118	1.0	121
Total	Extension agent	463	472		472
Ghana	Output dealer	139	141	1.0	139
Kenya	Output dealer	95	141	1.5	143
Mali	Output dealer	229	141	0.6	137
Nigeria	Output dealer	120	141	1.2	144
Total	Output dealer	583	563		563
Ghana	Input dealer	82	131	1.6	131
Kenya	Input dealer	112	131	1.2	134
Mali	Input dealer	207	131	0.6	124
Nigeria	Input dealer	124	131	1.1	136
Total	Input dealer	525	525		525
Total	**All intermediaries**	**1571**	**1560**		**1560**

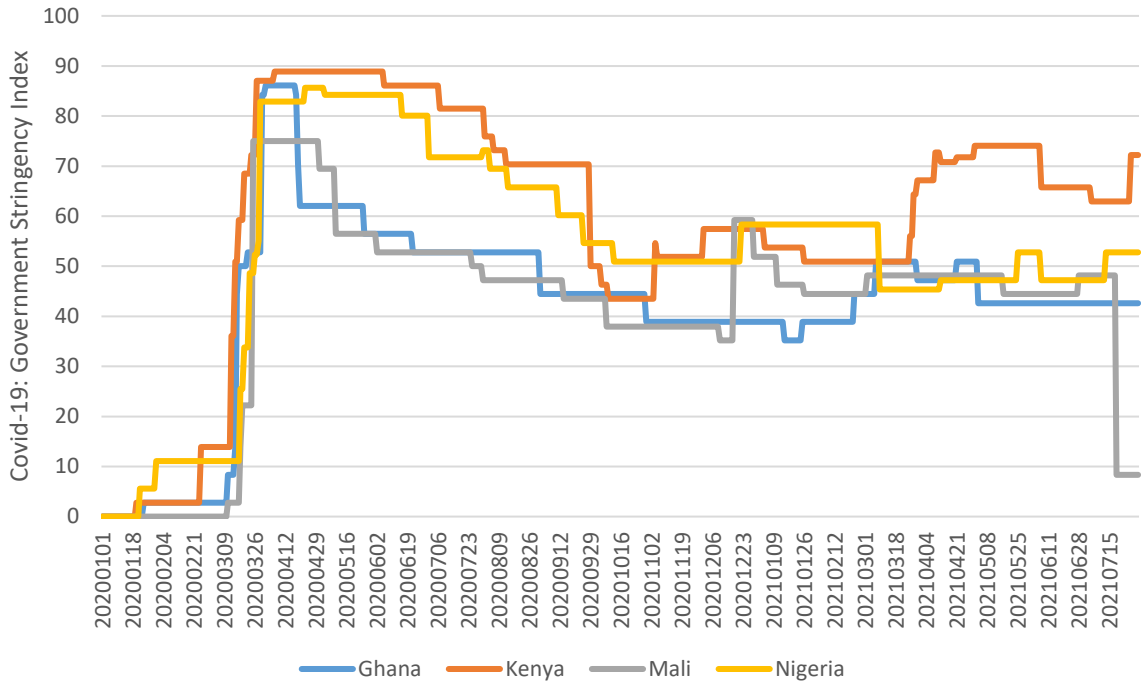
Table A2: Sample characteristics

		Extension Agents			Output Dealer			Input Dealer			Total		
		N (original)	N (weighted)	Share (weighted)	N (original)	N (weighted)	Share (weighted)	N (original)	N (weighted)	Share (weighted)	N (original)	N (weighted)	Share (weighted)
Country	Ghana	82	115	24	139	139	25	82	131	25	303	385	25
	Kenya	89	116	25	95	143	25	112	134	26	296	393	25
	Mali	171	120	25	229	137	24	207	124	24	607	381	24
	Nigeria	121	121	26	120	144	26	124	136	26	365	401	26
	Total	463	472	0	583	563	0	525	525	0	1571	1560	0
Age group	18-24	2	3	1	38	38	7	38	38	7	78	78	5
	25-29	56	56	12	48	48	9	59	59	11	163	163	10
	30-34	110	106	22	51	51	9	69	69	13	230	230	15
	35-39	83	83	18	74	74	13	81	81	15	238	238	15
	40-44	49	48	10	91	91	16	80	80	15	220	220	14
	45-49	37	36	8	97	97	17	71	71	14	205	205	13
	50-54	54	57	12	80	80	14	53	53	10	187	187	12
	55-59	62	72	15	54	54	10	30	30	6	146	146	9
	60-64	9	10	2	29	29	5	20	20	4	58	58	4
	65+	1	1	0	21	21	4	24	24	5	46	46	3
Level of education	no education	0	0	0	138	138	25	69	69	13	207	207	13
	primary school	1	1	0	151	151	27	79	79	15	231	231	15
	secondary school	12	11	2	147	147	26	113	113	22	272	272	17
	post-secondary	450	459	97	147	167	30	264	279	53	861	905	58
Sex of the respondent	Male	314	312	66	420	375	67	409	386	74	1143	1072	69
	Female	149	159	34	163	188	33	116	141	27	428	488	31

Cont.

		Extension Agents			Output Dealer			Input Dealer			Total		
		N (original)	**N** (weighted)	**Share** (weighted)	**N** (original)	**N** (weighted)	**Share** (weighted)	**N** (original)	**N** (weighted)	**Share** (weighted)	**N** (original)	**N** (weighted)	**Share** (weighted)
Mobile phone ownership	Yes	461	469	100	581	561	100	524	526	100	1566	1556	100
	No	2	2	0	2	2	0	1	1	0	5	5	0
Type of phone	Basic	60	130	28	120	172	31	118	198	38	298	500	32
	Feature	48	115	24	211	210	37	107	151	29	366	477	31
	Smartphone	443	448	95	360	350	62	424	417	79	1227	1216	78
Combination of phones	Only basic phone	7	6	1	79	80	14	40	50	9	126	136	9
	Only feature phone	13	11	2	141	131	23	54	49	9	208	191	12
	Only smartphone	357	368	78	256	260	46	307	304	58	920	932	60
	Basic and feature phone	0	0	0	3	4	1	7	8	2	10	12	1
	Basic and smartphone	51	51	11	37	36	6	71	74	14	159	161	10
	Feature and smartphone	33	33	7	66	51	9	46	42	8	145	126	8
	Basic, feature and smartphone	2	1	0	1	1	0	0	0	0	3	2	0
Main commodities (top 3)*	Maize	229	238	31	145	153	19	275	289	38	649	681	29
	Rice	44	40	5	101	99	13	26	27	4	171	166	7
	Vegetables	30	37	5	31	31	4	31	37	5	92	106	5

Figure A1: Stringency index for governments' Covid-19 containment measures (Jan 2020 – July 2021)



Note: The Stringency Index is a composite measure of nine of the response metrics. The index on any given day is calculated as the mean score of the nine metrics, each taking a value between 0 and 100. A higher score indicates a stricter response (i.e. 100 = strictest response).
Data source: Hale et al. (2021), downloaded 15 June 2022.

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Published by:
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