



Digital inclusion and performance of informal firms in sub-Saharan Africa

Damien Girollet

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**INCLUSION DIGITALE ET PERFORMANCES DES ACTIVITÉS
INFORMELLES EN AFRIQUE SUBSAHARIENNE**

Sous la codirection de
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Title: Digital inclusion and performance of informal firms in sub-Saharan Africa

Abstract: Despite decades of economic growth and the implementation of formalization reforms, informality remains a persistent feature of sub-Saharan African economies. To address the developmental issues generated by these segmented labor markets, the ongoing digital transformation of these economies has emerged as having some potential. Using first-hand or secondary quantitative survey data, the three chapters of this thesis aim to provide further empirical evidence on how informal firms use and benefit from these new technologies. The first chapter investigates the determinants of digital inequalities within sub-Saharan African informal sectors, questioning the potential adverse effects of an uneven diffusion of digital technologies rooted in pre-existing socio-economic inequalities. The second chapter explores how the most basic professional usage of digital technologies, namely bilateral communication with trading partners, affects the firms' economic performance and value-chain structure. Based on panel data collected in the informal sector of Dakar, the third chapter investigates more extensively how the different dimensions of mobile technologies' appropriation are associated with firms' dynamics and economic performance. The results support the need for greater consideration of digital technologies in policy interventions targeting informal enterprises, to harness their performance-enhancing effects and to prevent the new forms of exclusion they introduce.

Keywords: Informal sector, microenterprises, digital technologies, ICT, digital divide.

Titre : Inclusion digitale et performances des activités informelles en Afrique subsaharienne

Résumé : Malgré des décennies de croissance économique et la mise en œuvre de réformes de formalisation, l'informalité reste une caractéristique persistante des économies d'Afrique subsaharienne. Pour répondre aux problèmes de développement générés par ces marchés du travail segmentés, la transformation digitale en cours de ces économies est apparue comme offrant un certain potentiel. En utilisant des données quantitatives de premières et secondes mains, les trois chapitres de cette thèse s'emploient à fournir des preuves empiriques supplémentaires sur la façon dont les entreprises informelles utilisent et tirent profit de ces nouvelles technologies. Le premier chapitre étudie les déterminants des inégalités digitales au sein des secteurs informels d'Afrique subsaharienne, s'interrogeant sur leur imbrication dans les inégalités socio-économiques préexistantes. Le deuxième chapitre explore la manière dont le recours le plus élémentaire aux technologies digitales, à savoir la communication bilatérale avec les partenaires commerciaux, affecte la performance économique de ces entreprises et la structure de leur chaîne de valeur. Basé sur des données de panel collectées dans le secteur informel de Dakar, le troisième chapitre étudie plus en détail comment les différentes dimensions de l'appropriation des technologies mobiles sont associées à la dynamique et à la performance économique de ces entreprises. Les résultats soulignent l'importance d'une plus grande intégration des technologies digitales dans les politiques ciblant les entreprises informelles, à la fois pour exploiter leurs effets positifs sur les performances et pour prévenir les nouvelles formes d'exclusion qu'elles génèrent.

Mots-clés : Secteur informel, micro-entreprises, technologies digitales, TIC, inégalités digitales.

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General Introduction

Half a century ago, Keith Hart (1973) coined the concept of “informal sector” in a seminal article describing the source of livelihoods of rural migrants joining the urban labor force of Ghana’s capital, Accra. Based on the observation that only a small proportion of urban workers were concerned by wage employment in regulated private and public sectors, this pioneering study emphasized the significance of other “informal income opportunities” derived from self-employment in small-scale activities that lay beyond the scope of the official regulations. At the same time, the International Labour Office (ILO) report on employment in Kenya (ILO, 1972) extended the consideration of informality to all economic activities that did not fit within the formal framework. Embedded in a normative vision of formality, the genesis of this formal/informal dualism defined the informal sector as an unregulated sector made up of economic activities having obverse characteristics that modern capitalist enterprises. Although these early formulations of informality were reductive (Bromley, 1978), they triggered a shift in consideration of labor markets in developing countries, shedding light on the principal means of livelihood of non-farm workers.

Over the following decades, informality became a key concept in development economics. It generated intense theoretical and conceptual debates (Dell’Anno, 2022), finally leading to a widely accepted definition of the informal sector. This definition may be derived from the resolutions adopted by the 15th International Conference of Labor Statisticians (ICLS) (ILO, 1993), which identified a set of criteria referring to the economic units’ characteristics. Non-compliance with formal laws and regulations remains central in

the differentiation between formal and informal enterprises¹. Thus, the informal sector regroups all non-agricultural unincorporated enterprises, selling at least some of their production on the market, that are not registered with national authorities and/or do not keep formal accountability. This lack of legal status, which is generally associated with tax evasion, does not imply that the goods and services sold on the market by these businesses are illegal. Hence, formal and informal enterprises often coexist in industries, in both rural and urban areas, but are distinct, at least in their level of compliance with formal rules, which remain national-context specific. More recently, the focus on units of production has been overcome, and the notion of informality has been extended to employment status. The concept of informal employment encompasses all workers without formal social protection, and therefore without a formal written employment contract, whether they work in the informal or formal sectors (ILO, 2003). The informal economy then refers to a combination of these two concepts (Cling et al., 2012).

While informality was part of a dual vision of labor markets inherited from the two-sector models of development (Lewis, 1954; Harris and Todaro, 1970), recent literature has acknowledged its internal heterogeneity. On the one hand, the dichotomy arising from the legalistic definition of informality conceals a concrete continuum in the level of compliance with formal rules. Informality is thus a matter of degree, with some economic activities operating entirely outside of the formal regulation, while others do not meet every criterion to be considered formal (Benjamin et al., 2012; Williams et al., 2016). On the other hand, informality heterogeneity lies in the various reasons for which an individual may operate in the informal economy, essentially resumed by two lenses through which the origins and causes of informality are perceived (Perry, 2007). First, for the “exclusion” view, informality is the main form of economic activity due to the exclusion of a large part of the population from the formal economy. According to the dualist school, the informal sector only exists because of a lack of formal jobs, and this mismatch in labor markets is amplified by the significant population and urban workforce growth in developing countries. Thus, although symptomatic of poverty, the predominance of informality

¹A size criterion was also initially adopted, as informal production units generally operate on a small scale.

constitutes an intermediate stage of economic development, in which the informal sector serves as a reservoir of labor that economic growth should gradually allow to be absorbed into the formal economy. The legalistic school, popularized by the analysis of Latin American countries of De Soto (1989, 2000), is also partially in line with the exclusion lens. It argues that burdensome and inappropriate regulations introduced by formal institutions prevent many entrepreneurs from operating in the formal sector, thereby hindering the exploitation of their full economic potential. Hence, the formalization of the economy can be achieved by lowering entry barriers to formality, mainly by reducing registration and compliance costs. Second, for the “exit” view, operating informally is a voluntary individual choice derived from a rational cost-benefit analysis (Maloney, 1999, 2004). Informal firms intentionally exit the formal sector as they consider that formality costs, such as registration costs, official tax payments, and compliance costs with business and labor regulations, exceed the perceived benefits of formality. As the legalist school argues, the policy implications of such a view of informality include reducing the costs of formality. It also implies the necessity to increase its benefits, or the salience of the existent ones, and to improve the enforcement capacity of national authorities. Initially considered competing views, recent economic literature has recognized their coexistence and complementary for understanding informality (Ulyssea, 2020).

Over the past two decades, most policy interventions implemented to address the challenges of informality in developing and emerging countries have therefore consisted in promoting the formalization of firms and workers. Various types of interventions ranging from lowering entry and ongoing costs of formality, increasing its benefits, and strengthening enforcement of taxes and regulations have been implemented (Ohnsorge and Yu, 2022; Jessen and Kluve, 2021). However, in practice, most firms remain informal, and existing literature relying on randomized experiments provides mixed results according to the nature of the interventions (Ulyssea, 2020; Jessen and Kluve, 2021; Floridi et al., 2020; Campos et al., 2023). Furthermore, despite rapid economic growth in most low- and middle-income countries, the informal economy has not been absorbed by the formal economy as predicted by dual economy models, making informality a

persistent phenomenon in these labor markets (Kanbur, 2017; Gutiérrez-Romero, 2021; Danquah et al., 2019). It is particularly the case in sub-Saharan Africa, where informality remains a stylized feature of economies and is more pervasive than in other emerging markets and developing economies (EMDE) regions (Ohnsorge and Yu, 2022). On average, informal employment reached 76.8% of total non-agricultural employment in 2016 (Bonnet et al., 2019), while informal output represented 36% of official GDP in 2010-2018 (Ohnsorge and Yu, 2022). Despite a slight decline over the last two decades (Ohnsorge and Yu, 2022; Gutiérrez-Romero, 2021), the informal economy seems destined to persist for a while, whatever the optimism of the macroeconomic scenarios (Roubaud, 2013).

Governments seek to formalize the economy to broaden the tax base, thus increasing fiscal resources and integrating more accurately a large part of the non-observed economy into national accounts (Joshi et al., 2014), as well as to strengthen the sense of the rule of law (Everest-Phillips, 2008). Yet, the primary motivation to address informality challenges lay in the existence of significant overlaps between informality, low productivity, and poverty (Kanbur, 2017). Indeed, the literature has highlighted some stylized facts about the characteristics of informal activities that seem common across different contexts and regions (Cling et al., 2012). Compared to their formal counterparts, informal firms are, on average, less productive and of smaller size in terms of workforce and generated revenue (Hsieh and Olken, 2014; Gutierrez and Rodriguez-Lesmes, 2023). Higher economic, institutional, and social constraints induced by their informal status drive these performance differences, illustrated by lower access to physical capital, skilled workforce, banking, and public services (Grimm et al., 2011b). Hence, informality remains associated with poverty. While not all informal workers are poor, given the productive heterogeneity of informal enterprises and associated employment status (Grimm et al., 2012; Dasgupta and Lloyd-Jones, 2018), overall productivity differentials translate into significant wage gaps between formal and informal jobs (Meghir et al., 2015; Nordman et al., 2016; Nguyen et al., 2013). It is also driven by the over-representation of vulnerable parts of the population in informal employment, particularly the low-educated, young,

and women (Bonnet et al., 2019). As well as offering lower levels of livelihood, informal jobs are intrinsically vectors of vulnerability, resulting in unsafe working conditions, lack of social protection, unequal economic opportunities, and exclusion from social dialogue (De Vreyer and Roubaud, 2013). Thus, addressing informality also aims to achieve greater social and economic inclusion by offering more decent work opportunities.

The development challenges associated with informality are particularly acute in sub-Saharan Africa. With high demographic growth rates and migration flows to urban areas, non-agricultural labor markets' capacity to provide sufficient decent and remunerative jobs is still central to pursuing an inclusive and sustainable development process (Choi et al., 2020; World Economic Forum, 2017). Yet, informality remains the main, and often the only, possible source of livelihood for the population exiting the agricultural sector, acting as a safety net against extreme poverty. It is also the case for youth, facing a lack of formal wage employment opportunities and structural underemployment, despite the constantly rising level of human capital (Fox et al., 2016). Further, the political implications of the pervasiveness of informality are reinforced by the increasingly global risks threatening African economies. The Covid-19 crisis illustrates their vulnerability to external global shocks since it pushed around 30 million people into extreme poverty in sub-Saharan Africa, reversing the downward trend observed since the beginning of the century (Abay et al., 2023). Early evidence demonstrates that informal workers and small businesses were the most affected, probably due to limited social protection coverage (Schotte et al., 2023; Bundervoet et al., 2022). Climate change and natural disasters constitute more structural global risks to which sub-Saharan Africa is particularly vulnerable, notably due to disastrous effects on the agricultural sector (Hallegatte, 2016; Azzarri and Signorelli, 2020). By potentially increasing rural-urban migration (Barrios et al., 2006), climate shocks risk strengthening the pressure on the non-agricultural labor markets and consequently enhancing the role of the informal sector in generating income in African economies.

The persistence and worsening of the development issues raised by the predominance of informal employment resonate with the limited efficiency of formalization reforms

and call for different short to medium-term policies to address informality challenges (Roubaud, 2013). First, given their higher vulnerabilities to short-term idiosyncratic and covariate shocks, rapidly providing informal workers access to social protection schemes constitutes a key challenge that gained increasing attention (Guven et al., 2021; Riisgaard et al., 2022; Lund, 2020). Second, while extending social protection coverage to the informal economy would reduce the burden of costly coping strategies, policy interventions targeting informal enterprises also seem essential to help them overcome the economic, institutional, and social constraints that hinder them from thriving and growing (Grimm et al., 2011b; Nguimkeu and Okou, 2020). While this paradigm shift requires governments to officially recognize the informal economy as a matter of public policy, an in-depth understanding of how informal activities are organized and operate, accounting for their heterogeneity and complexity, is needed to design evidence-based policies.

In this sense, the last five decades of academic research have brought major advances in the conceptualization, measurement, and understanding of informality (Dell'Anno, 2022). However, along with the persistence of high informal employment prevalence, the study of informal activities is denoted by the constancy of their characteristic features and the unresolved issues they face (Hugon, 2014). These persistent structural features contrast with the profound transformations actually affecting the landscape in which sub-Saharan African informal activities operate. In this respect, the transformation of their technological environment, led by the rapid spread of telecommunication infrastructures and mobile phones, is striking. While informality was traditionally associated with simple technology (Cirera et al., 2022), the ongoing digital transformation of their environment is expected to bring new opportunities to enhance informal workers' livelihoods (Choi et al., 2020), but also raises new risks in the form of digital exclusion or adverse incorporation (Ragnedda, 2019; Heeks, 2022). While empirical evidence on the digital technologies' welfare effects at the household level is growing (Bahia et al., 2023), evidence on the digital inclusion of informal firms remains sparse. In this context, this thesis aims to provide original empirical evidence on how informal firms in sub-Saharan Africa use

these digital technologies for business purposes, and whether these practices help them overcome the constraints they face and boost their economic performance. The remainder of this general introduction presents key contextual elements describing the evolution of the digital environment of African economies, theoretical expectations about benefits and risks emerging with the proliferation of digital technologies, and the outline and contributions of the thesis.

1. Challenges to digital inclusion in African economies

Since the second half of the 20th century, rapid technological progress in digital electronics has paved the way for a wide range of innovations in digital technology, i.e., the representation of information as binary digits in a computer system (Dufva and Dufva, 2019). As defined by the World Bank (2016, p.2), these digital technologies regroup all the “tools to collect, store, analyze, and share information digitally”. It encompasses a wide range of devices, such as mobile phones, personal computers, and tablets, as well as all the applications and services derived from the processing of digital information by these devices. Digital technologies rely fundamentally on a vast ecosystem of information and communication technologies (ICT) infrastructures that provide wired and wireless telecommunications services, among which mobile telephony and the internet play a key role.

The inclusion of African economies in the digitalization process depends mainly on their infrastructural access to digital technologies. After lagging far behind in the deployment of ICT infrastructures, most African countries implemented major telecommunications policy reforms in the early 2000s. Previously dominated by national monopolies with limited investment capacity, the telecommunications sectors have been subject to extensive liberalization and privatization initiatives supervised by new national telecommunications regulatory authorities (Djiofack-Zebaze and Keck, 2009). These policy reforms have coincided with a significant increase in private sector investment in

the ICT sector in sub-Saharan Africa, driven by unmet demand in these emerging markets (Moshi and Mwakatumbula, 2017). These massive but late investments have enabled African countries to benefit from a technological leapfrogging, directly deploying wireless telecommunications without incurring the heavy expenses associated with investing in fixed-line infrastructures (James, 2009). Nowadays, most African countries have been catching up with other regions in this domain, with mobile-cellular network coverage nearing saturation in 2022 (ITU, 2022), and most African adults (83%) now owning a mobile phone (Afrobarometer, 2021)².

In contrast, Africa is lagging far behind in terms of internet penetration, with only around 39.7% of the population using the internet in 2022. Yet, recent and ongoing infrastructure investments, notably through submarine cables and subsequent terrestrial infrastructures deployment (Cariolle, 2020), have resulted in significant connectivity improvement, with 82% of the population living in areas covered by at least a 3G mobile broadband network (ITU, 2021). The emergence of cost-effective, high-performance satellite connectivity, driven by the recent deployment of Low Earth Orbit (LEO) satellites, should help to reduce the remaining coverage gap by providing connectivity in hard-to-reach areas (GSMA, 2022). However, mobile broadband coverage drops substantially when considering 4G or equivalent high-speed connectivity networks, as only half of the African population is covered by such a network (ITU, 2021).

While massive additional infrastructure investments must be made to achieve the provision of a universal “meaningful connectivity,” defined as a fast³ and unlimited daily broadband connection from a smartphone (Alliance for Affordable Internet, 2021b), an inclusive digital transformation involves more than universal access to reliable digital connectivity. While the coverage gap is shrinking rapidly, a large proportion of the population is not using the internet despite being covered by a mobile broadband network. This usage gap highlights the need for considering digital inclusion as a complex phenomenon, encompassing a range of supply-side and demand-side factors determining

²The estimated prevalence of mobile phone ownership is derived from nationally representative data collected in 2019-2021 from 48,082 adults in 34 African countries as part of Round 8 of the Afrobarometer surveys.

³Considering as a minimum threshold a 4G equivalent speed of mobile connectivity.

individuals' ability to access and use digital technologies. This ability depends on the availability of digital infrastructures, but also on the broader accessibility of digital technologies. In Africa, where computer ownership is particularly rare, the pervasiveness of mobile phones turns them into the main device for accessing the internet. However, mobile internet is only fully accessible from advanced devices such as smartphones, which are much less widespread than basic mobile phones and feature phones⁴. In 2021, only 43% of individuals in the region owned a mobile phone with internet access (Afrobarometer, 2021).

Hence, material access remains a major challenge in the digital transformation of African economies, which is closely tied to the affordability of digital devices, with smartphones remaining inaccessible for many. In Africa, individuals have to spend on average at least 39% of their monthly income to buy a new smartphone, in stark contrast to other regions of the world (Alliance for Affordable Internet, 2022). If the recent launch of entry-level smartphones tailored for African markets by operators is expected to expand smartphone ownership rapidly⁵, guaranteed access to reliable digital infrastructures and advanced devices constitute only the first steps to ensure digital inclusion. Indeed, despite significant improvement for all mobile usage baskets in recent years, Africa remains the region with the least affordable ICT services (ITU, 2022). Botswana, Mauritius, and Nigeria are currently the only African countries meeting the accessibility target set by the UN Commission on Broadband for Sustainable Development of 2% of monthly GNI per capita for entry-level broadband service⁶ (ITU, 2022). The data and voice high-usage basket, enabling individuals to benefit from at least 140 minutes of voice, 70 SMS, and 2GB of high-speed data in a month, also lacks affordability in most African countries. The median basket minimum price for such ICT services reaches 14.7% of monthly GNI per capita in Africa, against less than 4% in other regions (ITU, 2022). By preventing data-related and advanced usage of digital technologies, lack of affordability

⁴Feature phones are “internet-capable mobile devices that resemble earlier mobile models with tactile keyboards or keypads and only support basic applications” (Alliance for Affordable Internet, 2021a).

⁵Since 2020, operators such as Orange and MTN have launched low-cost smartphones priced at around US\$30 (Alliance for Affordable Internet, 2022).

⁶Considering a data-only mobile-broadband basket including monthly data allowance of at least 2GB.

still constitutes a strong constraint to digital technologies usage, particularly for the low-income population, that should be overcome.

In addition, bridging the usage gap implies improving the accessibility of digital technologies, which is more closely related to demand-side factors. Apart from basic literacy, using digital technologies often requires specific digital skills and capabilities to appropriately use the services and content they deliver. (Van Deursen and Van Dijk, 2014). Data on the level of digital skills in Africa is scarce but indicates that the skills gap between African countries and those in other regions is considerable (ITU, 2021). It implies that providing digital skills education and implementing an accessible digital environment, in terms of ease of use, relevance of content, and accessibility features, must remain political priorities to achieve digital inclusion in African countries.

The combination of all these factors partly explains why African economies are lagging behind other regions in digital transformation, but also implies the existence of disparities across African countries. Alongside regional digital leaders such as Kenya and South Africa, other countries, particularly among the least developed countries (LDC) and landlocked countries (LLC), are lagging impressively behind in terms of digital transformation (Dutta and Lanvin, 2022). While low-income countries are particularly prey to digital exclusion, this unequal distribution of digital opportunities also occurs within national boundaries. These digital inequalities, or digital divides, manifest themselves in the form of total or partial exclusion from the digitalization process, in terms of access, use, or tangible benefits, of individuals with specific socio-economic, demographic, or geographical characteristics (Lythreatis et al., 2021; Ragnedda, 2019). In Africa, while access inequalities mainly concern rural areas due to lower access and quality of ICT infrastructures (Buys et al., 2009; ITU, 2021), disparities in digital technologies usage are generally related to gender, education attainment, and income level (Ochoa et al., 2022). Hence, the proliferation of digital technologies does not only come with opportunities, but also with new challenges and risks. While the techno-deterministic view considered that achieving universal physical access to digital connectivity will be sufficient to drive societal change (Cammaerts and Van Audenhove,

2003), digital inequalities across populations having the same digital connectivity coverage, but not the same resources to access, use, and benefit from digital technologies, are expanding. These digital inequalities are often embedded in socio-economic inequalities, meaning that disadvantaged segments of the population risk experiencing exacerbated exclusion if they cannot access the transformative opportunities provided by digital technologies (Ragnedda et al., 2022; Rothe et al., 2023).

In this regard, the digital inclusion of informal actors is of prior importance. While they are already excluded from the benefits of having a formal status, informal workers are particularly vulnerable to digital exclusion due to a lower ability to access, use, and benefit from digital technologies than their formal counterparts. Indeed, while low levels of income and unstable financial resources make informal workers specifically vulnerable to lack of affordability of ICT devices and services, their generally low level of skills and education may imply limited access to the different dimensions of digital literacy, skills, and competencies that hinder their usage of digital technologies and benefits they get from the digital experience (Van Deursen and Van Dijk, 2010). Their exclusion, or partial inclusion, into the digital transformation risks widening their vulnerability and deepening the productivity gap with their formal counterparts (Nguimkeu and Okou, 2021). However, the entrepreneurial and productive heterogeneity within the informal sector implies that all informal workers do not have the same opportunities to embrace digital technologies in their business operations (Bhattacharya, 2019), potentially leading to a digital divide between the different fringe of informal activities, with the risk that most vulnerable informal workers being left behind.

2. Empowering informal enterprises through digital technologies

In pursuing Sustainable Development Goals (SDGs), digital inclusion for all is crucial, given the potential of digital transformation to foster inclusive economic development

(World Bank, 2016). Indeed, digital technologies, especially the internet, are considered general-purpose technologies due to their large-scale economic impact induced by the technological change they provide (Bresnahan and Trajtenberg, 1995; Cardona et al., 2013). The advent of these pervasive technologies has led to profound economic and social changes in all spheres of society, with the result that the exclusion of part of the population not only risks reproducing existing inequalities but also curbs economic progress.

During its early phase, technological progress related to ICT did not seem to produce the expected productivity gains, leading to a productivity paradox (Brynjolfsson, 1993), well illustrated by the widely cited statement from Robert Solow: “You can see the computer age everywhere except in productivity statistics” (Solow, 1987). Meanwhile, economic literature has provided empirical evidence on the ICT’s positive contribution to economic growth in the context of developed countries and, more recently, in the context of developing countries (Röller and Waverman, 2001; Waverman et al., 2005; Niebel, 2018; Stanley et al., 2018; Goldbeck and Lindlacher, 2021). Moreover, growing evidence tends to demonstrate that digital technologies diffusion holds significant potential for enhancing economic and social progress in developing countries, through positive effects on a wide range of outcomes, including poverty reduction, job creation, education and health services provision, and democracy (Hjort and Tian, 2023; Zhuravskaya et al., 2020; Bertschek et al., 2015). The economic opportunities that emerge from the spread of digital technologies can be apprehended using existing economic theory, by emphasizing what this technological change implies for economic activities (Goldfarb and Tucker, 2019).

Fundamentally, digital technologies transform how information flows in the economy, from analog to digital format, making it easier, faster, and cheaper to find and compare information. Indeed, while personal travel has often been the most common mechanism used to search for information, digital technologies have substantially reduced search costs (Goldfarb and Tucker, 2019). On the one hand, compared to personal travel, which implies high transport and opportunity costs, mobile telephony significantly reduces communication costs. It also allows for more proactive search processes, resulting in more immediate and personalized access to information than media, such

as newspapers and radio (Aker and Mbiti, 2010). On the other hand, by providing access to an infinite amount of non-rival information, the internet greatly contributes to the global diffusion of knowledge (Goldfarb and Tucker, 2019). This better information dissemination is theoretically expected to have a wide range of economic benefits, specifically by improving the functioning of markets through better coordination between economic agents, and a reduction in transaction costs (Brynjolfsson and Hitt, 2000). Hence, the digitalization of information flows is expected to help overcome information frictions to which African economies are particularly vulnerable. These economic benefits should grow in magnitude with the pervasiveness of such technologies due to network externalities, stressing the importance of achieving digital inclusion for all. In addition, digital technologies are service delivery platforms, providing access to specific content and services in various areas such as education, health, entertainment, and finance, among others (Aker and Mbiti, 2010).

Hence, digital technologies may provide economic opportunities by reshaping how individuals communicate and access information, but also by potentially integrating all dimensions of economic activity. Particularly, the theoretical benefits related to digital technologies diffusion have significant implications for the production side of the economy. Indeed, although the adoption of such technologies can also have some welfare-enhancing effects for consumers (Rodríguez-Castelán and Pierola, 2022), the economic literature identifies a large set of complex channels through which firms' and workers' economic activity may be affected. Following Hjort and Tian (2023), these channels can be distinguished into three broad categories depending on whether they affect the firm's productivity, production costs, or market access. First, digital technologies can potentially affect the firm's production process, with higher digitalization of business operations allowing firms to produce more with the same quantity of inputs. Improved firm productivity may come from the interaction between digital technologies and production factors. Specifically, recent empirical evidence from developing countries tends to demonstrate that internet-related digital technologies lead to labor-biased technical change, improving the efficiency of labor inputs Hjort and Tian (2023). Along

with factor-specific productivity, adopting digital technologies can potentially increase total factor productivity, through improved management and organizational practices, for example. Second, digital technologies are likely to affect firms' activity in ways other than enhanced productivity. On the supply side, by improving coordination with suppliers, digital technologies can affect the quality, quantity, and price of production inputs available to the firm. It may be due to better market coordination and an overall reduction in transaction costs resulting from the use of digital technologies, but also from the firm's improved ability to search for and find better supply channels in terms of price and quality. Finally, on the demand side, digital technologies are expected to expand the market reach of firms by creating new sales channels and reducing information friction with consumers.

An extensive strand of literature has already demonstrated that the roll-out of mobile telephony and the internet is associated with a wide range of economic benefits for smallholder farmers and agricultural markets in developing countries (Aker, 2011; Aker and Fafchamps, 2015; Aker et al., 2016; Deichmann et al., 2016; Abate et al., 2023). Although empirical evidence on the effects of digital technologies adoption on firm-level outcomes is growing rapidly (Hjort and Tian, 2023), existing studies mainly consider formal firms or informal small- and medium-sized activities. However, informal microenterprises represent most production units in many developing countries (La Porta and Shleifer, 2014). Given the specificities of informal activities in terms of productive structure and the constraints they face, more empirical evidence is needed to understand the implications of digital technologies' proliferation for these activities. Indeed, digital technologies appear to provide new avenues for tackling informality challenges. In line with traditional formalization policies, which aim to induce the transition of informal firms and workers to the formal economy, digital technologies constitute new tools for improving public service delivery and the enforcement of formal regulations (Aker and Cariolle, 2022). Specifically, e-government initiatives such as the digitalization of taxation systems and registration procedures can potentially induce greater participation in the formal economy (Elbahnasawy, 2021; Haruna and Alhassan, 2022). However,

these initiatives raise major concerns as they can have unintended negative consequences affecting the most vulnerable (Okunogbe and Santoro, 2023; Roy and Khan, 2021; Lahiri, 2020). Further, in association with the long-term policy target of formalization, digital technologies can be leveraged to implement short- to medium-term policies aiming at upgrading informal firms' productivity, and overcoming the barriers that hinder them from growing (Nguimkeu and Okou, 2021). While the digital inclusion of informal actors is challenging due to significant barriers to access and use, the benefits they can reap from using these technologies are at least as important as their formal counterparts. Indeed, the theoretical economic benefits described previously apply to informal activities, and may be particularly relevant given their specific organizational structure and constraints.

First, due to the weakness of formal institutions, interpersonal relationships and social networks play an essential role in structuring informal economic activities to access resources and cope with market failures (Fafchamps, 2004). In this context, digital technologies can potentially foster the efficiency of social exchanges based on interpersonal relationships by facilitating information dissemination and coordination (Fafchamps, 2006). Furthermore, as digital technologies allow to bypass face-to-face meetings to interact with trading partners, more regular business interactions can build mutual trust leading to lower transaction costs, but also provide the opportunity for informal firms to expand their trading networks with less locally and socially embedded business relationships (Molony, 2009). Using digital technologies for business purposes should enable informal enterprises to benefit from greater market efficiency and opportunities for inclusion in less socially embedded output and input markets, helping them improve their economic performance (Berrou and Combarrous, 2012). Second, lack of financial inclusion appears as a binding constraint for informal firms, resulting in low access to capital and credit (Grimm et al., 2011a; Wellalage and Locke, 2016). By adopting digital technologies, informal firms can benefit from financial technology innovations like mobile money. Apart from improving the security and liquidity of existing transactions and enabling transactions that would never have existed otherwise (Suri, 2017), such digital financial services participate in alleviating credit constraints and improve financial

inclusion of informal firms, notably by improving access to external sources of financing and saving mechanisms (Ahmad et al., 2020). Third, the low productivity of informal firms is often associated with the weakness of their internal resources, particularly in terms of management practices (McKenzie and Woodruff, 2017). While the use of digital technologies supports the management of external transactions with trading partners, advanced digital devices also provide access to a wide range of applications that can help informal firms improve their inventory management, record keeping, financial planning, or human resources management (Atiyas and Dutz, 2021). Moreover, digital technologies can be considered innovation inputs, as they may integrate the firm's innovation process. Indeed, by improving firms' access to knowledge, notably through the internet, digital technologies provide opportunities to learn new practices and production techniques, acquire new skills, or find inspiration and advice. By improving informal firms' management and innovation capacity, digital technologies are expected to bring opportunities to improve their economic performance (Cirera et al., 2016).

3. Contributions and outline of the thesis

Despite the disruptive nature of the technological change induced by the advent and rapid proliferation of digital technologies, empirical evidence on the digital inclusion of informal enterprises in developing countries has been slow to emerge. While the consequent delay in digital diffusion in developing countries, particularly in sub-Saharan Africa, may explain the scarcity of empirical evidence over the past two decades (Esselaar et al., 2006; Deen-Swararray et al., 2013), the increasing prevalence of these technologies in the landscape of informal labor markets prompts further interest in the issue. This thesis aims to contribute to narrowing this gap, by providing a better understanding of how informal businesses in sub-Saharan Africa are engaged in the digital transformation occurring in the region. Specifically, in light of the contextual elements outlined above, the thesis seeks to investigate two intertwined research questions. First, the dissertation investigates the existence and determinants of digital inequalities among informal firms.

The main hypothesis is that the heterogeneity of informal businesses and entrepreneurs should lead to significant disparities in digital inclusion opportunities, rooted in pre-existing socio-economic inequalities (Ragnedda et al., 2022). It should lead to a digital divide between the different fringe of informal activities, with the risk that the most vulnerable informal workers will be left behind. Second, the thesis investigates whether the use of digital technologies may explain some of the performance disparities observed across informal firms. In line with recent empirical evidence (Eekhout et al., 2022; Danquah and Owusu, 2021), the main assumption states that informal firms using digital technologies for business purposes should effectively benefit from better economic performance. Further, digital technologies may affect informal firms' performance in a complex and extensive way, as the multidimensionality of technology appropriation should interact with a wide range of firms' dimensions.

The thesis is embedded in a long-standing body of literature in development economics that contributes to shedding light on the determinants of the economic performance of microenterprises operating in developing countries. Particularly, the thesis participates in the recent strand of literature that explores the associations between digital technologies uses and informal firms' economic performance in sub-Saharan Africa (Danquah and Iddrisu, 2018; Danquah and Owusu, 2021; Berrou et al., 2020; Atiyas and Dutz, 2021; Eekhout et al., 2022; Atiyas and Dutz, 2023). As the dissertation seeks to identify the channels and mechanisms through which digital technologies affect the economic activity of informal microenterprises, the empirical analysis is also deeply rooted in the field of digital economics and ICT4D⁷ literature (Goldfarb and Tucker, 2019; Heeks, 2017). In this line, the digital inclusion of informal firms is approached from a usage perspective throughout the thesis. In contrast with the techno-deterministic view, this thesis assumes that the effects of digital technologies depend mainly on how individuals appropriate them, which is, in turn, socially determined (Ragnedda et al., 2022). It implies the necessity to go beyond material access, as the use of digital technologies by small businesses may be motivated by specific purposes, pursued through different features at varying levels of

⁷Information and Communication Technologies for Development.

intensity (Berrou et al., 2020; Atiyas and Dutz, 2021; Eekhout et al., 2022; Atiyas and Dutz, 2023). Given the - a priori - low level of digital inclusion of informal firms, the focus is on the use of digital technologies for general business support functions (Cirera et al., 2021), i.e., uses enabling relevant tasks to be carried out regardless of the sector of activity. In addition, due to the focus on digital inequalities, the thesis is also part of the digital divide literature (Lythreatis et al., 2021; Van Dijk, 2020). Thus, the empirical analysis takes into account the heterogeneity of informal firms and entrepreneurs, a necessity to study digital inequalities among this specific population, but also to provide more in-depth evidence on the terms of inclusion afforded by digital technologies to informal actors (Mann and Meagher, 2017; Bhattacharya, 2019; Nguimkeu and Okou, 2021).

The thesis contributes to these different bodies of literature by providing original empirical evidence. First, the dissertation adds to the literature on the digital divide by extending its theoretical framework to informal firms in sub-Saharan Africa, focusing on the second-level digital divide, i.e., the differences in digital technologies usage (Hargittai, 2002). Factors affecting this level of digital divide have been widely studied at the individual, regional, and national levels, but evidence at the firm level is scarce, especially in the context of developing countries (Lythreatis et al., 2021). Second, it provides additional empirical evidence of the enhancing effects of digital technologies uses on informal firms' performance, which complements the existing literature in several ways. Acknowledging the endogeneity of digital technologies usage, the empirical approaches implement instrumental strategy and fixed-effect panel regressions to provide rigorous empirical evidence. To date, only Danquah and Owusu (2021) have provided empirical evidence addressing endogeneity issues in the relationship between digital technologies and informal enterprise performance. The thesis also helps demonstrate the great potential of digital technologies to overcome the barriers that constrain informal enterprises, by embracing a more comprehensive conceptual framework. In line with a few recent studies (Berrou et al., 2020; Atiyas and Dutz, 2021; Eekhout et al., 2022; Atiyas and Dutz, 2023), it recognizes the multifaceted nature of digital technology appropriation, in particular in relation to the different economic functions that they provide. The thesis

further fills a gap in the existing literature by identifying some channels through which digital technologies influence the economic performance of informal firms.

Such an empirical approach requires specific survey data that provide detailed information on informal production units and the entrepreneurs' professional uses of digital technologies. Such data is scarce, as informal business surveys rarely ask about the various dimensions of digital inclusion, or do so at most through mobile phone ownership and internet use. In this context, only the After Access business surveys conducted by Research ICT Africa (2020) in 2017-18 provide the opportunity to explore the digital technologies uses of informal firms through a cross-country perspective. Indeed, these recent establishment surveys are based on harmonized sampling frames and questionnaires, and have specific modules questioning the various professional functions that digital technologies can perform. The survey covers eight African countries: Senegal, Ghana, Nigeria, Rwanda, Kenya, Tanzania, Mozambique, and South Africa⁸. The thesis also relies on a panel survey drawn from a research program, coordinated by Jean-Philippe Berrou from *Les Afriques dans le Monde*⁹ (LAM) and funded by the research department of Orange Innovation, which aimed at providing new insights on access to and use of mobile technologies by informal entrepreneurs in the Dakar region of Senegal. The panel data comprises two waves of a non-farm business establishments survey collected by the CRDES¹⁰ of Dakar, the baseline taking place in 2017 and the second wave in 2019. These two survey waves constitute an original representative panel data of an urban informal sector, with a large set of standardized questions about informal entrepreneurs' uses of digital technologies. The author of this thesis contributed directly to the second survey wave project by designing and supervising data collection, and conducting empirical investigations parallel to the analysis presented in this thesis. Both datasets are derived from informal establishment surveys and, consequently, do not provide a representative picture of what informal activities encompass. Indeed, the sampling frames omit the

⁸This thesis does not pretend to cover the entire sub-Saharan Africa through these eight countries alone, which, in addition to not offering a representative image of the subcontinent, all representing special cases beyond the similarities that can be attributed to them. A detailed presentation of countries is provided further in Chapter 1.

⁹Sciences Po Bordeaux - UMR CNRS 5115.

¹⁰Centre de Recherche pour le Développement Économique et Social.

most hidden activities, such as those behind the door of entrepreneurs' homes, as well as itinerant activities, such as street vendors. Although omitting the most vulnerable informal activities can lead to an optimistic and biased view of informality, any mixed survey providing a representative snapshot of informal activities has yet included the measurement of the use of digital technologies. Hence, the three chapters presented in this thesis consider a common observation unit: non-farm informal activities operating in a fixed and visible place.

The dissertation follows a progressive approach structured in three chapters that provide original empirical evidence on key issues related to the digital inclusion of informal firms. **Chapter 1** investigates to what extent informal firms in sub-Saharan African countries use digital technologies for business purposes and, specifically, whether the productive heterogeneity of informal firms is related to digital inequalities. The After Access business surveys conducted by Research ICT Africa (2020) in 2017-18 are used to answer these questions. This dataset allows us to provide extensive descriptive evidence on the level of digital inclusion of African informal businesses, by considering the diversity of devices and functions offered by digital technologies. In order to confront the heterogeneity of informal firms with their digital inclusion, several classification approaches are adopted. The empirical strategy follows the approach proposed by Grimm et al. (2012) to identify three informal segments in each country: top performers, constrained gazelles, and survivalists. The robustness of this classification is tested by comparing its results with those of a multidimensional clustering approach and an index of firms' degree of informality. After identifying the three informal business segments according to their socio-demographic and productive characteristics, the descriptive analysis reveals significant gaps in access and usage of digital technologies between the three segments, with the lower fringe of the informal sector lagging behind. To gain insight into these descriptive findings, a multivariate analysis is conducted to identify the main determinants of digital technologies usage for business purposes, considering entrepreneurs' and firms' characteristics. Further, a multivariate decomposition for

nonlinear response models is used to identify common and segment-specific levers for addressing digital inequalities in usage across the different segments of informal firms.

In addition to highlighting digital inequalities that reflect pre-existing socio-economic inequalities in the informal sector, these initial analyses reveal that the advanced uses of digital technologies, such as the use of the internet or digital financial services, are not widely adopted by informal firms in sub-Saharan Africa. Instead, they use digital technologies mainly to communicate with their business partners through basic calls and text messages. Hence, **Chapter 2** aims to estimate the effect of digital technologies usage for bilateral coordination with trading partners on the economic performance of informal firms. The empirical analysis also draws on the After Access business surveys conducted by Research ICT Africa (2020). As the use of digital technologies has the potential to reshape the way informal firms communicate, access and provide information, and conduct transactions along their value chain, the main assumption is that bilateral coordination with trading partners has a significant and positive impact on informal firms' economic performance, measured as total monthly sales. To address endogeneity issues, a two-stage least squares (2SLS) estimation is performed, relying on two instrumental variables that reflect the stage of diffusion of these technologies in the firm's local area. Subsequently, the existence of a third-level digital divide, which suggests that individuals benefit differently from using digital technologies depending on their characteristics (Scheerder et al., 2017), is tested. Specifically, the chapter investigates whether digital bilateral coordination has distributional effects on firms' sales, and whether there are heterogeneous effects in terms of gender, location, level of informality, and firm size. Further, the potential pathways through which digital technologies can affect informal firms' economic performance are investigated using simultaneous equation models (3SLS). Two assumptions are tested: (1) whether bilateral coordination strengthens existing business relationships, thereby reducing transaction costs and increasing the social capital of informal firms, (2) and whether this usage extends the market reach of firms by reshaping their business network.

In order to shed light on the potential of other dimensions of digital technologies appropriation, **Chapter 3** extensively investigates the relationship between the professional uses of digital technologies and small firms' economic performance. The empirical analysis relies on the panel data collected in the informal sector of the Dakar region in Senegal. The data allows for a more detailed measure of the professional usage of digital technologies. It considers answers to 32 questions collected in both survey waves, mainly related to the use of mobile technologies. The data makes it possible to assess for what purposes informal entrepreneurs use these technologies, how they accomplish these tasks, and at which intensity level. Using different measures of technology appropriation, the empirical analysis first examines how stable mobile technologies usage is over a two-year period, and to which extent professional usage of digital technologies is associated with firms' survival and subsequent sales growth. Second, it analyzes whether mobile technologies usage is associated with higher firm economic performance in the informal sector of Dakar, considering monthly sales and value-added as dependent variables. Panel data models with fixed effects (FE) estimators are used to address the omitted variable bias likely to occur in that relationship. Third, different channels through which digital technologies may affect small firms' economic performance are explored. The assumption states that these technologies have the potential to overcome some constraints faced by informal firms and, thus, indirectly affect their economic performance. Using the panel data, the associations between digital technologies and the following intermediate outcomes are explored: registration and tax payment status, access to credit, capital accumulation dynamics, and innovation behaviors.

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Chapter 1

Digital Divides among Micro-Sized Firms: Evidence from sub-Saharan Africa

Abstract.

This chapter explores digital inequalities in access and usage among 3,300 firms and entrepreneurs from eight sub-Saharan African countries. To account for informal firms' heterogeneity, we identify three segments: an upper tier of top performers, a lower tier of survivalists, and an intermediate segment composed of constrained gazelles. Although digital technologies are already used by most of the informal entrepreneurs in sub-Saharan Africa, our findings suggest that the diffusion of these new technologies is uneven across informal firms, digital inequalities being rooted in pre-existing socio-economic inequalities. Indeed, digital inequalities align with the vertical heterogeneity of informal sectors in each country and are associated with entrepreneurs' and firms' characteristics. Using multivariate analysis, we find that the gender and educational gaps in digital usage observed at the individual level persist in the productive sphere. At the same time, firms with the highest level of informality, low profits, precarious operating conditions, no access to financial services, and less developed value chains are less likely to use digital technologies. The decomposition of usage gaps between segments of informal entrepreneurs reveals that there are both common and segment-specific levers for addressing digital inequalities.

1. Introduction

With an average informal employment rate of 76.8% in 2016 (Bonnet et al., 2019), informality is a persistent feature of sub-Saharan African economies. To tackle this phenomenon, most implemented policies have focused on the formalization of firms and workers, resulting in a wide range of fiscal and business environment reforms (Floridi et al., 2020). However, most firms remain informal, and existing literature relying on randomized experiments provides mixed results according to the nature of the interventions and the context (Ulyssea, 2020; Jessen and Kluve, 2021; Floridi et al., 2020; Campos et al., 2023). While pro-formalization programs consider the transition to formality necessary to generate productivity gains, increase fiscal resources, and achieve greater economic and social inclusion, recent literature argues for a shift towards policies that consider the reverse causal direction (Choi et al., 2020; Nguimkeu and Okou, 2021; Kanbur, 2017; Roy and Khan, 2021). Short to medium-term policies should focus on pro-productivity interventions to induce sustainable formalization, as activities will not formalize unless they grow (Nguimkeu and Okou, 2021). In this context, the ongoing digital transformation of African economies is expected to bring new opportunities to enhance informal firms' performance (Choi et al., 2020).

Indeed, an emerging strand of literature demonstrates that informal firms in sub-Saharan Africa significantly benefit from the use of digital technologies in terms of economic performance (Berrou et al., 2020; Eekhout et al., 2022; Danquah and Owusu, 2021). However, digital diffusion also brings new challenges and risks that can impede or reduce the benefits associated with digital transformation. If digital connectivity has dramatically progressed since the major telecommunications policy reforms implemented in the early 2000s (Moshi and Mwakatumbula, 2017; Howard and Mazaheri, 2009), investment in telecommunications infrastructure will not be enough to promote digital inclusion for all in sub-Saharan Africa. Depending on supply-side and demand-side factors, the diffusion of digital technologies is uneven and generates digital inequalities - or digital divides - between and within countries (Mutsvairo and Ragnedda, 2019; Van Dijk, 2020). Initially

defined as “the divide between those with access to new technologies and those without” (NTIA, 1999), the digital divide was firstly imbued with some technological determinism, in the belief that the universal dissemination of digital technologies is inevitable and would solve particular problems in the economy and society (Chandler, 1995; Gunkel, 2003). However, this prior consideration is no longer relevant as it has become clear that digital divides continue to expand even after physical access becomes universal (Donner, 2015). Notably, the literature shows that digital divides have emerged across populations having the same physical access to digital technologies, depending on individuals’ socio-economic and demographic characteristics (Hargittai, 2002). This second-level digital divide is often an extension of pre-existing socio-economic inequalities, making digital inclusion a social rather than a technological challenge (Ragnedda and Muschert, 2013). As a result, the diffusion of digital technologies may not necessarily imply greater inclusion. It may induce the opposite effect by leading to the emergence of new inequalities and the reproduction of existing ones (Ragnedda et al., 2022; Van Dijk, 2017).

While they are already excluded from the benefits of having a formal status, informal entrepreneurs are particularly vulnerable to digital exclusion due to a lower ability to access, use, and benefit from digital technologies (Esselaar et al., 2006; Cirera et al., 2021). Their exclusion, or partial inclusion, into the digital transformation risks widening their vulnerability and deepening the productivity gap with their formal counterparts (Nguimkeu and Okou, 2021). Furthermore, different forms of mobile technologies appropriation among informal micro and small enterprises in the informal sector of Dakar have been identified (Eekhout et al., 2022). Given the entrepreneurial and productive heterogeneity of informal activities, all informal workers probably do not have the same opportunities to embrace digital technologies in their business operations (Bhattacharya, 2019), potentially leading to a digital divide between the different fringes of informal sectors. Such a new dimension of inequality not only risks exacerbating the pre-existing socio-economic inequalities in informal sectors, but also curbs the expected productivity gains and greater economic inclusion that digital transformation must provide to informal actors.

In this chapter, we investigate the existence and determinants of digital inequalities in usage within African informal sectors. Specifically, we examine whether informal business heterogeneity is reflected in digital inequalities, implying that uneven digital diffusion reproduces pre-existing socio-economic inequalities. For this purpose, we rely on the After Access business surveys conducted by Research ICT Africa (2020) in 2017-18 among 3,300 firms and entrepreneurs in eight sub-Saharan African countries¹. This dataset allows us to provide extensive descriptive evidence on the use of digital technologies by African informal businesses, considering three major functions for which they can use these technologies as described by Berrou et al. (2020): the external coordination function, the financial function, and the internal management function. In order to confront the heterogeneity of informal firms with their level of digital inclusion, the empirical strategy follows the approach proposed by Grimm et al. (2012) to identify three informal segments in each country: top performers, constrained gazelles, and survivalists. The robustness of this classification is tested by comparing its results with those of a multidimensional clustering approach and an index of firms' degree of informality. After describing the segments of informal firms according to their socio-demographic and productive traits, the descriptive analysis reveals significant gaps in access and usage of digital technologies between the segments. To gain insight into these descriptive findings, a multivariate analysis is conducted to identify the main determinants of digital technologies usage for business purposes, considering entrepreneurs' and firms' characteristics. We conduct this analysis for the whole sample and then for each informal segment, to observe general and segment-specific determinants of digital inequalities. Finally, we use a multivariate decomposition for nonlinear response models (Yun, 2004; Powers et al., 2011), to decompose segments differences in the probability of using digital technologies into disparities in observable characteristics, on the one hand, and disparities in the effect of these characteristics, on the other.

¹Senegal, Ghana, Nigeria, Rwanda, Kenya, Tanzania, Mozambique, and South Africa.

We find evidence of significant heterogeneity among microenterprises in sub-Saharan Africa. Apart from having specific entrepreneurial and productive characteristics, the three segments display strong disparities in their level of digital inclusion. The lower tier of survivalists is the most digitally excluded, both in terms of access to and usage of digital technologies. Conversely, the most successful firms, the so-called top performers, largely embrace digital technologies in their way of doing business. Despite being almost as well equipped and having similar socio-demographic characteristics and entrepreneurial behaviors as top performers, firms in the intermediate segment still exhibit a lower use of digital technologies than the most successful firms. Thus, digital inequalities align with the vertical heterogeneity of informal sectors in sub-Saharan Africa, and are associated with some characteristics of entrepreneurs and firms. The multivariate analysis finds a significant gender gap in the use of digital technologies for business reasons, with female-led businesses having lower usage levels than others. Education attainment also appears to be an essential determinant of digital inequalities, confirming the importance of basic literacy in using computers and mobile phones, and in accessing specific digital skills (Hargittai, 2002; Van Deursen and Van Dijk, 2010). Concerning firms' productive characteristics, we find that those with the highest level of informality, low profits, precarious operating conditions, no access to financial services, and less developed value chains are less likely to use digital technologies. These results show that digital inequalities are congruent with socio-economic inequalities traditionally observed among African informal firms. Nevertheless, the usage gap between top performers and the two other segments is not associated with similar factors according to the results of the multivariate decomposition. When comparing survivalists and top performers, the second-level digital divide seems to be driven by differences in the various dimensions of access (Van Dijk, 2017). Survivalists make less use of digital technologies than top performers due to lower motivation, lower material access, lower skills, and higher financial constraints. Conversely, the usage gap between constrained gazelles and top performers is largely driven by differences in their ability to afford digital services. While differences in material access and motivation also contribute to the usage gap between

these two segments, internal constraints, such as entrepreneurial or digital skills, do not seem to play a significant role given their similar entrepreneurial characteristics.

The remainder of this chapter is organized as follows. Section 2 provides a literature review of digital divides and their determinants across individuals and firms in sub-Saharan Africa. Section 3 describes the data and the conceptual framework for observing the professional uses of digital technologies. Section 4 presents the segmentation methods and the empirical strategy to identify the determinants of the second-level digital divide. The results are presented in Section 5, and Section 6 concludes.

2. Literature review

2.1 Digital divides definition

The digital divide concept initially referred to the gap between those who have and those who do not have access to certain forms of information and communication technologies (NTIA, 1999), mainly computers and the internet. The concept now also encompasses other digital technologies, hardware, and software, such as feature phones and smartphones (Van Deursen and Van Dijk, 2019). Initially, most studies considered this binary distinction between haves and have-nots, focusing on disparities in physical access (e.g., infrastructures and devices) across demographic groups and countries (Van Dijk, 2006; Riggins and Dewan, 2005). This access gap, referred to as the first-level digital divide, considered mainly digital inequalities through a narrow perspective, reducing access inequalities to mere technological and economic issues, which should disappear over time with market liberalization and deployment of telecommunication infrastructures (Thierer, 2000; Norris, 2003; Fuchs and Horak, 2008).

However, some scholars have argued that providing universal physical access to digital technologies will not be enough to bridge the digital divide, which in fact, arises when the use of digital technologies becomes ubiquitous in daily life (Van Dijk, 2017). This shift towards a broader perspective in the interpretation of digital inequalities refers to

the second-level digital divide (Hargittai, 2002; Van Dijk, 2006). It aims to examine issues “beyond access,” considering that digital inequalities mainly occur within the group of digital technology users itself, due to disparities in quality of access, digital skills, and actual usage of digital technologies (Hargittai, 2002; Van Dijk and Hacker, 2003; DiMaggio et al., 2004; Van Deursen and Van Dijk, 2014; Hilbert, 2011). Recognizing the digital divide as a complex and multidimensional phenomenon (Van Dijk, 2006), the second-level digital divide has transcended the dichotomous “access approach,” by considering digital inequalities as a continuum with real social implications (Ragnedda, 2019). Since digital inequalities are linked to existing socio-economic inequalities and can exacerbate them, the digital divide is now a social issue rather than just a technological one (Ragnedda and Muschert, 2013; Van Dijk, 2017).

The resource and appropriation theory developed by Van Dijk (2005) is in line with this theoretical shift, moving beyond methodological individualism and adopting a relational or network approach instead (Van Dijk, 2017). The core argument of this theory is that digital inequalities in access, skills, and usage are rooted in already existing socio-economic inequalities, as the latter leads to an unequal distribution of resources and, thus, to inequalities in the process of appropriation of digital technologies. Moreover, these digital inequalities may bring unequal benefits and tend to exacerbate pre-existing inequalities. Indeed, even if access to and use of digital technologies do not automatically translate into tangible benefits, these first and second-level digital divides can also produce disparities in terms of social, economic, political, or cultural benefits, leading to a third-level digital divide (Scheerder et al., 2017). Following this assumption, Heeks (2022) recently proposed a new conceptual framework to understand the relationship between growing digital inclusion and digital inequalities in the global South. Through the concept of “adverse digital incorporation,” the author argues that inclusion in a digital system can lead to unequal benefits or even adverse outcomes for some groups and positive outcomes for others, resulting in greater digital inequalities despite growing digital inclusion.

2.2 Determinants of digital divides in sub-Saharan Africa at the individual-level

The determinants of the digital divide at the individual level have been widely studied in developed countries, but overlooked in sub-Saharan Africa, and often limited to demographic and socio-economic characteristics (Srinuan and Bohlin, 2011). Evidence suggests a rural-urban divide, consistent with findings in developed countries. Rural location is associated with lower access to and use of digital technologies, partly due to the lower mobile network and internet coverage, as remoteness and low population density make the deployment of terrestrial infrastructure less profitable than in urban areas (Buys et al., 2009). Similarly, access to a stable source of electricity appears to be a key factor in mobile phone ownership or internet adoption in West Africa (Forenbacher et al., 2019; Adeleke, 2021; Ochoa et al., 2022), highlighting the importance of complementary investment in electricity infrastructure to bridge the digital divide. This rural-urban divide can also be explained by the fact that income is an important determinant of digital inclusion in sub-Saharan Africa, as low-income households or individuals are less able to spend a significant portion of their income on digital devices or services (Birba and Diagne, 2012; Ochoa et al., 2022). Affordability of digital services and devices remains a strong demand-side constraint, with very few countries currently meeting the accessibility target set by the UN Commission on Broadband for Sustainable Development of 2% of monthly GNI per capita for entry-level broadband service (ITU, 2021).

The lack of skills and capabilities to use digital technologies is another important demand-side constraint. Thus, a lack of basic literacy is a barrier to digital inclusion, as most services and devices are designed for people who can read and write. Furthermore, knowledge of English or French is positively associated with greater digital inclusion, which can be explained by the greater availability of internet content in these languages (Ochoa et al., 2022; Pénard et al., 2015, 2012). More generally, because literacy and other digital skills are necessary to fully use and benefit from digital technologies, educational attainment appears to be a key determinant of digital inequalities (Deen-Swararray, 2016;

Birba and Diagne, 2012; Ochoa et al., 2022; Hasbi and Dubus, 2020; Pénard et al., 2015, 2012; Forenbacher et al., 2019).

Basic demographic characteristics are also significant determinants of the digital divide in sub-Saharan Africa. As in other regions of the world, a gender gap in the access and use of digital technologies is observed in most African countries (Ochoa et al., 2022; Birba and Diagne, 2012; Hasbi and Dubus, 2020; Pénard et al., 2015, 2012; Forenbacher et al., 2019; Gillwald et al., 2010). This gender gap may be due to differences in average digital skills or income levels, combined with social and cultural gender norms unfavorable to women (Hafkin and Taggart, 2001; Mumporeze and Prieler, 2017). Age of individuals is another common determinant of digital inequalities, with younger people being more likely to adopt digital technologies than older ones, probably due to higher education attainment and technology familiarity (Ochoa et al., 2022; Birba and Diagne, 2012; Hasbi and Dubus, 2020; Pénard et al., 2015, 2012; Forenbacher et al., 2019).

2.3 Digital divides among small firms in sub-Saharan Africa

There is little evidence on the level and determinants of the digital divide among firms in developing countries (Lythreatis et al., 2021; Srinuan and Bohlin, 2011). Yet the heterogeneous nature of these firms, which are for the most part informal microenterprises, has been widely recognized as a key feature for several decades (La Porta and Shleifer, 2014; Cunningham and Maloney, 2001). The literature traditionally distinguishes between subsistence and growth-oriented entrepreneurs, which differ in their motivations, socio-economic characteristics, growth potential, access to technology and capital, and level of financial inclusion (Benjamin et al., 2012; Schoar, 2010). Grimm et al. (2012) argues for the existence of another intermediate group, called constrained gazelles, next to the lower tier of subsistence entrepreneurs (or survivalists) and the higher tier of growth-oriented entrepreneurs (or top performers). Commonly considered subsistence entrepreneurs, these constrained gazelles operate at low levels of capital and performance but share similar characteristics and skills with the top performers, revealing

an untapped growth potential. Furthermore, addressing the firms' heterogeneity can also be done by going beyond the traditional dichotomy between formality and informality by recognizing the existence of a continuum of different levels of informality (Williams et al., 2016; Benjamin et al., 2012).

This heterogeneity in entrepreneurial attributes and productive characteristics may lead to significant additional digital divides (Bhattacharya, 2019). First, the uneven distribution of resources among informal firms may induce inequalities in their opportunities to access and use digital technologies for business purposes. The high cost of digital technologies is often the main barrier to adoption and use cited by firms in sub-Saharan Africa (Esselaar et al., 2006), highlighting that most firms face a lack of affordability of digital devices and services, potentially due to severe financial constraints such as low profits and no access to financial services. Thus, Atiyas and Dutz (2021) find that Senegalese micro-sized firms with access to bank loans are significantly more likely to own a smartphone. Moreover, the lack of knowledge and awareness of the potential benefits and the very existence of the new technologies may contribute to slowing down adoption, especially for advanced technologies or uses (Esselaar et al., 2006). In addition to some industry-specific adoption patterns, firm size, level of physical capital, and access to electricity also appear to be positively correlated with access and use of digital technologies (Cirera et al., 2021; Berrou et al., 2020; Atiyas and Dutz, 2021). Second, entrepreneurial orientation may induce specific patterns in the appropriation process of digital technologies. According to the technological acceptance theory, the motivation, attitude, and intention to accept and use digital technologies may vary due to differences in perceived advantage, usefulness, and ease of use (Van Dijk, 2005; Chuttur, 2009). Hence, growth-oriented entrepreneurs, who have entrepreneurial traits that encourage the search for and pursuit of opportunities, as well as better management of risks and uncertainties, are expected to be more receptive to new digital technology innovations and more likely to adopt them (Tang and Konde, 2020; Fafchamps and Quinn, 2018). Similarly, competition in the domestic market and industry-level adoption of new technologies can affect technology adoption at the firm-level through competitive concerns and spillover effects (Cirera et al., 2021). Finally, the

level of formality has been pointed out as a key determinant of digital inclusion, with higher compliance with formal regulations being associated with greater access and use of digital technologies (Cirera et al., 2021; Esselaar et al., 2006; Deen-Swararray et al., 2013).

3. Data and descriptive statistics

3.1 The data

We use data from the After Access business surveys conducted by Research ICT Africa (2020) in 2017-18 across eight African countries²: Senegal, Ghana, Nigeria, Rwanda, Kenya, Tanzania, Mozambique, and South Africa. After Access surveys include a household survey and a business survey, conducted in 2018 for Senegal and Tanzania, and in 2017 otherwise.

Household and business samples were generated randomly in each country, and the sampling procedure followed four steps³. First, based on a national census sampling frame, the enumeration areas (EA) in each country were separated into urban and rural ones. Second, the EA were sampled for each stratum using probability proportional to size. Third, a census of all households and businesses in that area was conducted for each selected EA. Then, for each selected EA, a number of households and businesses were randomly sampled from this sampling frame. Thus the households and businesses surveyed are not directly linked, as the survey design is not similar to a 1-2-3 survey. As no other selection criteria were used, such as filter questions associated with a definition of informal enterprises, not all businesses surveyed are necessarily informal. We restrain the sample of surveyed businesses to non-farm activities, as agricultural activities are specific in their mode of production and are few in the sample. In addition, we delete some observations due to missing values on key variables. The final sample considered in the following analyses comprises 3,300 firms from eight sub-Saharan African countries.

²Due to important missing values, observations from Uganda were excluded from the analysis.

³According to the technical documentation provided by RIA (2018).

Although businesses were randomly selected for the survey, they are not representative of the informal sectors in each country. Indeed, the sampling frame is only representative at the household level, as each EA has a household density of about 200. The distribution of businesses is not necessarily uniform within these EA, particularly because of the potential concentration of informal businesses within activity areas such as markets. Furthermore, the listing of all businesses in each selected EA omits the most hidden and elusive activities, those that take place in the homes of the entrepreneurs, as well as itinerant activities such as street vendors.

However, the data are particularly suitable for exploring in depth the level of digital inclusion of informal enterprises from diverse African countries with specific productive structures, business environments, or stages of digital technology diffusion. Indeed, harmonized surveys of informal enterprises in different countries asking them about their digital practices are valuable, and random sampling ensures the internal validity of the results.

The survey collects basic information on the firm's owner⁴ and his/her business, such as socio-demographic characteristics of the entrepreneur, registration status of the business, sector of activity, labor force, relationship with suppliers and customers, economic performance, and level of physical assets. Businesses' sales, expenses, profit, and value of capital reported by entrepreneurs are expressed in local currency, so price differences between countries are adjusted⁵ via Purchasing Power Parity (PPP) conversion factors and converted in international \$. In addition, the survey investigates entrepreneurs' access to and use of digital technologies, exploring the multidimensionality of devices, interfaces, and functions that entrepreneurs may mobilize for business purposes.

⁴Hereafter referred to as "entrepreneur."

⁵According to the year of the survey.

3.2 Macroeconomic and digital environment across countries

The informal enterprises in the sample are located in eight different countries in sub-Saharan Africa with specific structural and macroeconomic environments, and varying levels of digital technology diffusion. Table 1 reports these disparities for each country.

Of the eight countries considered, South Africa is a special case due to its upper-middle-income status. We also observe emerging economies with lower middle-income status, such as Nigeria, Ghana, and Kenya. Senegal moved up to lower-middle-income status in 2018 but is still part of the least developed countries, with Tanzania, Mozambique, and Rwanda. By considering these eight countries, we have a good representation of what sub-Saharan African countries are in terms of income levels but not a good representation in terms of geographical distribution. Indeed, we do not consider any countries from Central Africa, as the countries in the sample are located in West Africa, East Africa, and South Africa. These different levels of development are correlated with significant heterogeneity in terms of urbanicity, access to electricity, and literacy rates across countries. Except for South Africa, informality remains pervasive in all countries, with a high proportion of non-agricultural employment.

Infrastructural access is not a factor of inter-countries digital inequalities, as most of the population had access to at least a 3G mobile network coverage in 2017. While Nigeria and Senegal appeared to lag in 2017, the gap closed in 2018 as the proportion of the population with access to at least 3G coverage increased to 75.5% and 92%, respectively. More recent data shows that access to 3G or 4G networks is almost universal in all countries except Mozambique, Tanzania, and Nigeria, where between 25% and 15% of the population still lack access to such networks. Significant differences in the price of entry-level digital services confirm that affordability was an important barrier to the adoption and use of digital technologies in most of the countries in 2017. Along with these disparities in infrastructural access and affordability, we observe digital inequalities in terms of usage. South Africa and Mozambique, the most and least economically developed countries in the sample, are also the most and least advanced in terms of digitalization.

Indeed, while the spread of mobile telephony has been largely achieved in all countries, Mozambique is lagging behind. Conversely, half of South Africa's population uses the internet, significantly outpacing other countries. We also note the well-known high adoption of mobile money services in Kenya.

These inter-country disparities in terms of digital inclusion are summarized by two composite indices: the Network Readiness Index (Baller et al., 2016) and the ICT Development Index (ITU, 2017b). Both indices are based on a different conceptual framework that aggregates indicators of different dimensions for each economy related to the regulatory environment of the telecommunications sector and/or the level of access, use, and impact of digital technologies⁶. These internationally comparable indicators make it possible to compare the level of digital transformation between economies. The overall ranking confirms that sub-Saharan Africa remains the lowest-scoring region while displaying some heterogeneity among the countries in our sample. It confirms that South Africa is at an advanced stage of digital technology diffusion compared to other countries such as Tanzania and Mozambique. Thus, depending on the country, the informal enterprises in our sample do not benefit from the same macroeconomic environment, and the same level of digital diffusion. We intend to account for these differences between countries by including controls for regions within countries in our model specifications.

⁶The NRI is a composite indicator made up of 53 individual indicators, while the IDI considers 11 indicators.

Table 1: Structural characteristics and digital technology diffusion across countries in 2016-2017

	South Africa	Nigeria	Ghana	Kenya	Senegal	Tanzania	Rwanda	Mozambique
Structural characteristics								
Region	South	West	West	East	West	East	East	South
GNI per capita, PPP (constant 2017 Intl.\$) ^a	13564	4963	4687	4231	3168	2402	1874	1250
Income level category ^a	Upper middle	Lower middle	Lower middle	Lower middle	Low	Low	Low	Low
Informal employment (% of non-agri. employment) ^a	35	-	83	70	90	72	68	87
Urban population (%) ^a	65.9	49.5	55.4	26.6	46.7	33.1	17.1	35.5
Access to electricity (%) ^a	84.4	54.4	79.0	56.0	61.7	32.3	34.1	24.3
Adult literacy rate (%) ^a	87	62	79	81.5	51.9	77.9	73.2	60.7
Digital technology diffusion								
Population covered by at least a 3G mobile network (%) ^b	98.6	54	80	85	66.3	85	93.4	80
Mobile-cellular sub-basket (as % of GNI p.c) ^b	1.5	1.8	2.4	2.3	17.3	6.4	8.4	6.0
Mobile-broadband, prepaid handset-based, 500 MB (as % of GNI p.c) ^b	1.3	1.7	4.5	4.4	8.3	3.0	4.4	5.2
Mobile-cellular subscriptions per 100 inhabitants ^b	156	75	122	87	104	71	72	42
Active mobile-broadband subscriptions per 100 inhabitants ^b	70	20	78	35	28	9	35	27
Internet users (%) ^b	56	33	38	18	30	16	17	8
Have mobile money account (%) ^d	19	5.6	39	72.9	31.8	38.5	31.1	21.9
ICT index								
Network Readiness Index (Rank out of 143) ^c	65 (1)	119 (6)	102 (4)	86 (3)	107 (5)	126 (8)	80 (2)	123 (7)
ICT Development Index (Rank out of 176) ^b	92 (1)	143 (5)	116 (2)	138 (3)	142 (4)	165 (8)	153 (7)	150 (6)

Notes: The mobile-cellular sub-basket comprises approximately 50 minutes call time and 100 SMS messages per month. For the ICT indices, the ranking of the countries out of the eight observed is put in brackets.

Source: ^a World Development Indicators, World Bank (2017) ; ^b International Telecommunication Union, ICT Indicators Database, ITU (2017a), and ITU (2017b) ; ^c World Economic Forum, Baller et al. (2016) ; ^d Global Findex, Demiguc-Kunt et al. (2018).

3.3 Description of firms and entrepreneurs

Table 2 reports some characteristics of firms and entrepreneurs for the total sample and for each country. Although we observe significant differences across countries, it is difficult to draw any conclusions about the composition of countries' informal sectors, given that the samples for each country are not nationally representative⁷.

In the whole sample, the entrepreneurs are mostly sole proprietors of their businesses and are 38 years old on average. The proportion of firms led by women is slightly lower than that of men, while 8% of businesses are joint ventures between men and women. The data also shows that entrepreneurs' level of education remains low, with 36% of them having no education, and only 20% and 12% having reached secondary or tertiary education, respectively⁸. Half of the entrepreneurs state that the main reason for starting their business was the lack of other job opportunities, implying that they would have been unemployed and resourceless otherwise.

Most businesses are located in urban areas (63%). They have on average been set up for seven years and operate predominantly in the trade sector (68%). The vast majority of businesses are not considered by any type of registration. However, one-third of enterprises are registered with some local or municipal authorities, and just over one-tenth are registered at the national level. This is consistent with the fact that most of the firms in the sample are not subject to any form of taxation. Indeed, while 39% pay taxes at the local or municipal level, only 17% are registered for national VAT or sales tax. The data also provides information on one of the other main formality criteria considered in sub-Saharan Africa, namely keeping accounts in conformity with national or regional standards. It can be considered that only 5% keep advanced accounts that are probably compliant with standards, while 43% carry simple bookkeeping and the remainder none. This low level of formality is combined with low financial inclusion, as only 25% of businesses have access to a bank account.

⁷See Mothobi et al. (2020) for a cross-country description of the sampled enterprises and entrepreneurs.

⁸If there are several owners, we consider the one with the highest level of education. Similarly, for the owner's age, we consider the youngest owner.

Table 2: Characteristics of firms and entrepreneurs

	South Africa	Nigeria	Ghana	Kenya	Senegal	Tanzania	Rwanda	Mozambique	All
Entrepreneur characteristics									
Man	0.56	0.38	0.42	0.40	0.68	0.56	0.64	0.39	0.50
Woman	0.30	0.57	0.51	0.48	0.28	0.38	0.25	0.56	0.42
Joint venture (Woman and man)	0.13	0.04	0.07	0.12	0.04	0.05	0.11	0.05	0.07
Age	42.6	38.0	39.6	34.9	36.6	37.7	.	38.2	38.1
No education	0.09	0.28	0.18	0.02	0.51	0.68	0.55	0.47	0.36
Primary education	0.71	0.17	0.39	0.20	0.22	0.24	0.36	0.35	0.32
Secondary education	0.16	0.40	0.34	0.49	0.06	0.02	0.08	0.04	0.20
Tertiary education	0.04	0.15	0.08	0.29	0.21	0.05	0.02	0.13	0.12
No other opportunity	0.49	0.48	0.53	0.28	0.43	0.67	0.48	0.61	0.50
Firm economic performance^a									
Sales	1245	345	454	498	837	398	461	131	448
Value-added	527	129	235	280	586	187	169	28	205
Net profit	622	86	144	174	314	14	131	44	113
Firm characteristics									
# of full-time paid workers	2.9	1.5	2.2	2.1	2.5	1.4	2.2	1.2	2.0
Any full-time paid worker	0.36	0.79	0.54	0.59	0.49	0.74	0.59	0.86	0.63
One or two full-time paid workers	0.45	0.14	0.34	0.34	0.34	0.24	0.32	0.12	0.28
Three or more full-time paid workers	0.09	0.04	0.06	0.04	0.11	0.02	0.05	0.02	0.05
Five or more full-time paid worker	0.10	0.03	0.06	0.04	0.07	0.01	0.05	0.01	0.04
Physical capital ^b	1556	246	312	249	418	225	236	53	249
No capital	0.39	0.24	0.36	0.36	0.50	0.13	0.21	0.48	0.33
Urban	0.73	0.44	0.64	0.67	0.68	0.59	0.65	0.69	0.63
Manufacture	0.07	0.15	0.15	0.06	0.14	0.10	0.10	0.18	0.12
Service	0.27	0.18	0.20	0.26	0.21	0.15	0.24	0.07	0.20
Trade	0.65	0.67	0.65	0.69	0.64	0.75	0.66	0.76	0.68
Age of firm	5.7	7.6	6.8	3.6	6.1	4.8	17.6	6.0	7.1
Registration with any local or municipal authority	0.34	0.21	0.35	0.40	0.33	0.18	0.78	0.11	0.32
Registration at the national level	0.29	0.03	0.14	0.15	0.13	0.04	0.32	0.02	0.13
Pay local or municipal taxes	0.27	0.44	0.47	0.41	0.44	0.15	0.78	0.22	0.39
Registration for national VAT or sales tax	0.26	0.10	0.22	0.16	0.23	0.12	0.20	0.04	0.16
Formal accounts	0.06	0.02	0.01	0.01	0.21	0.02	0.02	0.02	0.05
Access to electricity	0.85	0.56	0.60	0.63	0.68	0.50	0.81	0.27	0.60
Bank account	0.55	0.26	0.32	0.28	0.14	0.09	0.38	0.10	0.25
Observations	364	492	387	388	470	457	349	393	3300

Notes: ^a Median values. ^b Median values among firms with non-zero capital. All monetary values are expressed in 2017 Intl.\$ PPP.

Source: Author's computations based on After Access Surveys, RIA, 2017-2018.

The firms we consider are mainly micro-sized, with 97% having less than five full-time paid workers, and 63% having any such employees. If the absence of labor force is often observed, this is also the case for fixed assets, as 33% of the entrepreneurs declare that they do not own any fixed assets of value (machinery, vehicles, furniture, etc.).

3.4 Global overview of digital technologies usage

Table 3 proposes an overview of access to and use of digital technologies for business purposes for the total sample and each country. We consider the first-level digital divide through the ownership of mobile phones, landline phones, and computers. These devices offer different possibilities of use through which one or more professional functions of digital technologies can be mobilized. As these different tools are not necessarily interchangeable, both in their specific uses and in the network of contacts that can be reached, the cumulative possession of these devices may offer entrepreneurs a greater capacity for use, and perhaps different benefits. The entrepreneurs in the sample widely own mobile phones, with a penetration rate of 79%, which is consistent with the fact that the access gap is narrowing in the region, making them increasingly ubiquitous (GSMA, 2021)⁹. Access to other ICT devices is extremely limited, with only 6% and 4% having access to a computer and a landline phone at the workplace, respectively, confirming the hegemony of the mobile phone and the limited penetration of other devices in sub-Saharan Africa. Overall, about 21% of the businesses in our sample do not have direct access to an ICT device, while the proportion of businesses with more than one ICT device only reaches 7%. Among firms that do not own a mobile phone, more than half claim they do not need one, and almost a quarter report that the main reason is that it is too expensive.

⁹The database does not allow for differences in the quality of devices owned by entrepreneurs, particularly between cell phones and smartphones. The ability of entrepreneurs to access a mobile broadband internet connection, a key determinant in internet access, is unknown. This figure, therefore, only guarantees access to basic telecommunication services for entrepreneurs.

Table 3: Digital technologies ownership and usage among surveyed firms

	South Africa	Nigeria	Ghana	Kenya	Senegal	Tanzania	Rwanda	Mozambique	All
Ownership of DT devices									
Mobile phone	0.92	0.66	0.78	0.87	0.89	0.81	0.67	0.7	0.79
Landline phone	0.14	0.02	0.04	0.01	0.09	0	0.01	0	0.04
Computer	0.19	0.01	0.05	0.03	0.1	0.03	0.04	0.02	0.06
Number of DT devices owned									
Any	0.07	0.34	0.21	0.12	0.11	0.19	0.31	0.3	0.21
One	0.7	0.63	0.72	0.84	0.77	0.77	0.66	0.68	0.72
Two	0.13	0.02	0.05	0.03	0.07	0.04	0.02	0.02	0.05
Three	0.1	0	0.01	0	0.05	0	0	0	0.02
DT usage for external coordination									
Bilateral coordination with suppliers	0.43	0.41	0.49	0.63	0.66	0.2	0.78	0.23	0.47
Bilateral coordination with customers	0.38	0.41	0.56	0.66	0.61	0.19	0.7	0.24	0.46
Multilateral coordination	0.28	0.09	0.13	0.11	0.23	0.06	0.05	0.03	0.12
DT usage for financial transactions									
Online or mobile banking	0.22	0.04	0.07	0.12	0.08	0.06	0.09	0.11	0.09
Mobile money to send money	0.05	0.02	0.25	0.56	0.31	0.11	0.42	0.12	0.22
Mobile money to receive money	0.03	0.02	0.28	0.41	0.24	0.13	0.4	0.2	0.21
DT usage for internal management									
Use of management software	0.09	0	0	0.01	0.07	0.01	0.02	0.01	0.02
Number of DT functions used									
Any	0.37	0.44	0.27	0.12	0.19	0.66	0.15	0.56	0.35
One	0.21	0.23	0.23	0.15	0.2	0.14	0.08	0.17	0.18
Two	0.18	0.26	0.21	0.26	0.25	0.08	0.34	0.14	0.21
Three	0.11	0.04	0.12	0.19	0.11	0.07	0.11	0.07	0.1
Four	0.05	0.02	0.11	0.18	0.1	0.03	0.23	0.04	0.09
Five	0.06	0	0.06	0.08	0.09	0.01	0.07	0.02	0.05
Six	0.01	0.01	0.01	0.02	0.04	0.01	0.01	0.01	0.01
Seven	0	0	0	0.01	0.01	0	0.01	0	0
Observations	364	492	387	388	470	457	349	393	3300

Source: Author's computations based on After Access Surveys, RIA, 2017-2018.

The second-level digital divide is observed through the use of digital technologies for professional purposes. No information was collected on digital skills, and incomplete information was collected on the different interfaces used and the intensity of use. While it limits our consideration of the multidimensionality of digital technologies usage, the diversity of use is already relevant in characterizing second-level digital inequalities among African microenterprises. Subsequent analyses then focus on the purposes for which firms use digital technologies, rather than the way or frequency with which they use them.

While 79% of firms have access to a mobile phone, only 65% use it for business purposes. Among enterprises that do not own a personal device, just over a third still report using digital technologies for business purposes. It highlights the complexity of assessing access to ICT devices in a context where shared devices and the interweaving of business and social spheres can provide opportunities for indirect access. Conversely, ownership of a mobile phone or other ICT devices does not necessarily imply professional use, as the use of digital technologies may remain confined to the social sphere. More than a quarter of enterprises with access to an ICT device do not use it for business reasons, illustrating the importance of going beyond access and observing actual usage. Given that most businesses have undergone some degree of digitalization by integrating digital technologies into their business operations, it is essential to explore for what purposes businesses use these technologies.

Following Berrou et al. (2020), we consider three major functions of digital technologies in the business context: the external coordination function, the financial function, and the internal management function. The external coordination function considers digital technologies as tools to improve market coordination with the firm's external partners. Businesses can use these technologies to communicate in a bilateral, or one-to-one, way in the context of interpersonal relationships. The available data allows us to consider whether businesses use digital technologies for bilateral coordination upstream of production with suppliers or downstream of production with customers. These uses are the most widespread among the sampled businesses, with 48% and 47% using digital

technologies for bilateral coordination with their suppliers and customers, respectively. These two specific uses of digital technologies are significantly correlated, as three-quarters of the firms that practice bilateral coordination with their suppliers also do it with their customers, and conversely. However, face-to-face communication remains the most common mode of communication for most entrepreneurs, as only 24% and 18% report preferring digital technologies to communicate with their suppliers and customers, respectively. It is confirmed by the fact that these technologies are most often used as a complementary communication tool to face-to-face communication rather than as a substitute, as few businesses (11%) exclusively use digital technologies to communicate with their suppliers.

Digital technologies also allow for more extensive market coordination through multilateral, or one-to-many, coordination. It concerns the use of digital technologies, and mainly the use of the internet, for information retrieval, online sales or advertising, and group or mass communication through social media. Multilateral coordination is much less common among the businesses in our sample, with only 12% of them reporting that they use the internet or social media for business purposes. Although low, this is in line with the proportion of people using the internet in Africa in 2017, which stood at only 21.8% (ITU, 2017b). Then, social media and internet use are advanced usages. In addition to requiring an internet-enabled device and affordable, high-quality connectivity, such uses require higher digital skills than those needed to communicate with suppliers or customers in a bilateral way.

Then, the financial function considers digital technologies as tools for financial inclusion, allowing people to benefit from financial services other than through banking and to carry out cashless financial transactions. Mobile money services are used for business purposes by 27% of the businesses in the sample. Among them, 77% receive transfers from their customers, and 63% pay their suppliers with these services. Some of these businesses also use mobile money to pay bills (48%), taxes (13%), or wages (14%). The use of mobile money for business purposes does not necessarily involve sending and receiving transfers, as 41% of service users are solely concerned with one type of transfer. In addition, the

intensity of mobile money use is low among the group of users, with only 13% of them receiving payments daily. Mobile banking, which offers digital access to financial services for those with bank accounts, is also considered, but the adoption rate stands at only 9%. It highlights the low financial inclusion of the businesses in our sample, with 57% of them neither having a bank account nor using mobile money services.

At last, the internal management function considers digital technologies as a tool for managing the firm's internal operations. We consider internal management through the use of software for inventory management, accounting, or performance monitoring. Implementing the use of such software requires significant resources in terms of digital skills and equipment, as we are specifically considering computer software. Given the few enterprises owning computers, the use of management software concerns only 2% of the firms surveyed.

Finally, this overview hides significant disparities between countries, as the level and pattern of digital diffusion among surveyed firms in each country vary. Access to ICT devices remains a major issue in the digital inclusion process in some countries, while access is now almost universal in others. Mobile phone ownership ranges from 66% in Nigeria to 92% in South Africa. Landline phone and computer ownership concerns the South African and Senegalese samples essentially, as these devices are almost absent in other countries. However, the access divide remains relatively narrow across countries compared to the usage divide.

The proportion of businesses using at least one of the functions of digital technologies for business purposes varies significantly between countries. Less than half of the businesses in Tanzania (34%) and Mozambique (44%) have digital practices. In comparison, three-quarters or more of the businesses are users in Kenya (89%), Ghana (74%), Rwanda (85%), and Senegal (81%). These inter-country disparities could be explained by differences between countries in terms of structural and macroeconomic characteristics, level of ICT infrastructure and accessibility, as well as characteristics of firms and entrepreneurs. However, the non-representativeness of the data at the national level does not allow us

to judge the determinants of these cross-country disparities, as they may be due to the structure of the samples in each country.

4. Empirical strategy

4.1 Heterogeneity of micro-sized firms: a deductive approach

To examine whether informal firms' heterogeneity is related to their level of digital inclusion, we rely on the method proposed by Grimm et al. (2012). This method, originally used to classify informal enterprises in the context of some West African countries (Grimm et al., 2012; Lavallée and Roubaud, 2019), has also been applied in other contexts such as the Democratic Republic of Congo by Adoho and Doumbia (2022), Ethiopia by Abebe et al. (2018), Mexico by Negrete (2022), and Morocco by Moosa (2019). The methodology follows a deductive approach as it assumes the existence of three distinct and homogeneous groups within the informal sector: (1) top performers, comprising a fixed proportion of entrepreneurs with the highest economic performance based on selected criteria; (2) constrained gazelles, who share similar characteristics with the top performers, but are far from their economic performance levels; and (3) survivalists, a group of subsistence entrepreneurs with fundamentally different characteristics and limited economic potential.

4.1.1 Defining top performers

We define top performers based on a combination of two criteria, as described in Grimm et al. (2012). First, in each country, we select the top 40% firms with the highest value of fixed physical capital. This size criterion allows us to identify businesses that have had the capacity and the motivation to grow in the past. The size criterion, therefore, reflects past performance and the propensity to invest in the business. In a way, it ensures that we retain growth-oriented entrepreneurs and firms with access to capital, two significant factors of success among micro and small enterprises (La Porta and Shleifer, 2014). The

second step consists of retaining from these firms the 50% with the highest net profit. This performance criterion aims to capture the current performance of the firm. This deductive method automatically assigns about 20% of the sampled firms to the group of top performers.

Our approach differs somewhat from that initially proposed by Grimm et al. (2012), which identifies the group of top performers by first selecting the firms in the top 25% of physical capital value distribution, from which they select the 40% of firms with the highest capital profitability. First, while we consider the same size criterion, we consider the net profit instead of capital profitability to assess the current economic performance of firms. We argue that in our context, where firms are mainly engaged in trade activities, capital productivity may not be the most suitable indicator for evaluating a firm's performance. We also prefer the firm's net profit over the turnover, as it measures the entrepreneur's net income and the firm's capacity to reinvest. Second, we adapt the thresholds to identify a group of top performers representing 20% of the sample and not only 10%. Compared to Grimm et al. (2012), which use 1-2-3 survey data, our sample of firms does not include the most vulnerable activities, such as household businesses or street vendors. Then, we argue that a 10% group of top performers is quite restrictive and risks assigning successful firms to the group of constrained gazelles.

4.1.2 Identifying constrained gazelles and survivalists

Then, our empirical method aims to capture the heterogeneity of entrepreneurs who have not been defined as top performers. While this group of remaining entrepreneurs is traditionally defined as subsistence entrepreneurs, here we want to identify among them the entrepreneurs with the potential to become successful. These entrepreneurs, called constrained gazelles, have similar characteristics to top performers. Therefore, constrained gazelles are entrepreneurs with a high empirical probability of being top performers, given their observable characteristics. Following Grimm et al. (2012), the probability of being a top performer is estimated by the following probit model:

$$Pr(Y_i^{TP} = 1) = \Phi(\beta_0 + X_i' \beta_1 + \omega_i), \quad (1)$$

where Y_i^{TP} is a dummy variable that takes the value 1 if the entrepreneur is a top performer, and 0 otherwise. X_i' is a vector of entrepreneur and firm characteristics. β_0 and β_1 are the vector of coefficients indicating how these characteristics influence the probability of being a top performer, and ω_i the error term. Finally, Φ is the cumulative density function of the standard normal distribution. Standard errors are clustered at the EA level.

To minimize endogeneity issues, the set of explanatory variables is limited to predetermined factors, i.e., characteristics that are observable prior to, or at the time of, the creation or starting management of the business by the entrepreneur. Although only predetermined factors are considered, we expect the model to identify a group of entrepreneurs, called constrained gazelles, with similar entrepreneurial behavior and characteristics to top performers, but clearly different from survivalists.

The predetermined factors considered as regressors in the model are the entrepreneur's gender and level of education¹⁰, urban location, whether the main source of initial capital used to start the business is microfinance or bank loan, and the motivation of the entrepreneur to set up the business. This last variable is measured by a dummy variable which takes the value 1 if the entrepreneur started the business because he or she had no other job opportunity, i.e., he or she would be unemployed otherwise. As in Grimm et al. (2012), in addition to these variables, we add controls for sectors and countries, as well as for the age of the firm.

Based on this binary response model, we predict for all the entrepreneurs in our sample the probability of being a top performer, using the estimated parameters $\hat{\beta}_0$ and $\hat{\beta}_1$, and the observed vector of entrepreneur and business characteristics:

¹⁰We do not include the entrepreneur's age due to missing data for all the sample of Rwanda. For the other countries, more than 90% of observations are assigned to the same group whether we consider or not the age of the owner in the model.

$$\widehat{Pr}(Y_i^{TP} = 1) = \Phi(\widehat{\beta}_0 + X_i' \widehat{\beta}_1), \quad (2)$$

where “hats” indicate estimated parameters. In order to segment the sample of entrepreneurs in each country into these three groups, we use the predicted probabilities in the following way.

For each country, we calculate the average predicted probability of the top performer group identified previously based on a double criterion of size and performance. The group of constrained gazelles must be defined in such a way that the average of the predicted probabilities of this group is identical to the average among the top performers. To do this, the second step consists of ranking the entrepreneurs not defined as top performers in descending order of their predicted probabilities. Then, starting with the non-top performer with the highest predicted probability, we add the following individuals until the average predicted probability of the constituted group is equal to the average predicted probability of the top performer group. Thus, the distribution of variables used as regressors in the model must be similar between the constrained gazelles and the top performers, indicating that these two groups share similar observable predetermined characteristics. The group of survivalists comprises entrepreneurs who are neither top performers nor constrained gazelles.

4.2 Alternative measures of heterogeneity

In the methodology described above, the choice of the criteria, the order in which they are applied, and the associated thresholds, partly determine the partition results. Although Moosa (2019) demonstrates that the modification in composition and characteristics of groups is limited when applying diverse alternative empirical specification¹¹, we test the robustness of our partition by comparing it with the segmentation resulting from a cluster analysis and an informality index.

¹¹Such as including only one criterion, inverse double-criteria, or choosing different thresholds.

4.2.1 Cluster analysis: an inductive approach

We rely on exploratory data analysis methods to let the segmentation emerge from the data with a minimum of prior structure imposed, by exploring the similarities (or dissimilarities) between individuals in a multidimensional perspective. To implement this inductive classification, we rely on a Hierarchical Classification by Principal Components (HCPC) as detailed by Husson et al. (2010).

In line with the literature on heterogeneity among informal firms in developing countries, we consider four broad classes of variables (12 variables) in this clustering approach (Cunningham and Maloney, 2001). First, we include some characteristics of the entrepreneurs with two variables indicating their education level and motivation to start the business. Second, we include five variables displaying the size of the firm and its economic performance: the value of the stock of physical capital used, the value of monthly net profit, and the value of monthly labor productivity¹², the number of full-time workers, and access to electricity on premises. The three continuous variables are grouped into terciles in each country, to ensure that the best-performing businesses in each country are assigned to the top tercile¹³. Third, as entrepreneurial traits and behaviors are expected to lead to heterogeneity in African informal sectors, three variables are added, including bookkeeping, separating business and personal finances, and having a bank account. Finally, the clustering approach considers the firms' participation in formal institutions through two variables: business registration and payment of taxes.

In the first stage, we use factor analysis as a pre-processing step for two reasons. First, factor analysis is used as a dimensionality reduction technique, which is relevant in our case, considering the large number of variables retained in the analysis and the complex relationships existing between them. Second, factor analysis allows the transformation of categorical variables into continuous ones. Due to the qualitative nature of the variables,

¹²Labor productivity is defined as value-added per worker. We consider the number of full-time workers and owners to compute this measure of firm performance.

¹³For the value of the stock of physical capital, we define terciles by considering only enterprises with a nonzero value. Firms without capital are grouped in a different category.

the factor analysis was carried out using Multiple Correspondences Analysis (MCA). As we applied factor analysis as a pre-processing step with the main objective of obtaining the coordinates of the individuals in each component, factor analysis results are not interpreted. Based on the Kaiser criterion (Kaiser, 1960)¹⁴, we retain the first eight dimensions, which reflect 58% of the total inertia.

We use the individuals' coordinates on these eight factors to carry out an Agglomerative Hierarchical Classification (AHC) to let a segmentation emerge from the data, categorizing entrepreneurs and their businesses into homogeneous groups. From the factor scores, the algorithm determines the Euclidean distances between individuals. Then, through Ward's criterion method, individuals are aggregated into clusters in order to minimize the within inertia.

The number of clusters is determined by analyzing the overall appearance of the hierarchical tree and the bar plot of within inertia gain. Partition into three groups is the most appropriate solution because the groups are homogeneous within themselves and distinct from each other. Solutions with five clusters, while providing inertia gains, constitute clusters of small size that could be less intelligible. Specifically, it divides the two extreme classes into two subgroups each, providing little additional information.

Although AHC is an effective clustering algorithm and allows the number of clusters to be determined without much user contribution, its results are not optimal and can be consolidated by k-means to maximize between-inertia. The partition obtained by the AHC is introduced as the initial partition of the k-means algorithm, which, after a few iterations, consolidates the partition.

4.2.2 Degree of informality

Microenterprise heterogeneity can also be explored by looking beyond the traditional dichotomy between formality and informality. Indeed, there are many types of formalization processes, such as registration, tax payment, and compliance with

¹⁴Which suggests retaining all dimensions whose inertia is greater than the average inertia.

accounting standards or labor regulations. These different processes are many ways to maintain formal relationships with institutional actors operating at the local, regional, or national level. Therefore, the formal/informal dichotomy does not seem to capture the complexity and diversity of the relationships that microenterprises have with formal institutions. This implies the need to consider instead a continuum of degrees of informality by combining several criteria to avoid an 'all or nothing' criterion.

In line with Williams et al. (2016), we construct an index of the level of informality of businesses by considering the following variables: (1) being registered with a local authority or municipality, (2) being registered at the general registrar, (3) paying local or municipal taxes (tax stamps), (4) being registered for national VAT or sales tax, and (5) keeping accounts according to national or regional standards. The cross-country nature of the survey implies that each of these criteria reflects different country-specific realities. This measure provides a six-point informality scale based on which we classify firms into four categories: totally informal, high level of informality, low level of informality, and formal¹⁵.

4.3 Determinants of the second-level digital divide

4.3.1 Multivariate analysis

To identify the main determinants of the second-level digital divide among microenterprises in sub-Saharan Africa, we rely on a standard logit regression model that estimates the effect of entrepreneur and firm-level characteristics on the likelihood of using digital technologies for business purposes. The dependent variable is a binary indicator taking the value 1 if the enterprise uses at least one of the following functions: bilateral coordination with suppliers, bilateral coordination with customers, multilateral coordination, sending money through mobile money services, receiving money through mobile money services, use of mobile or online banking, internal coordination through

¹⁵Totally informal firms meet zero criteria, high informal firms meet one or two criteria, low informal firms meet three or four criteria, and formal firms meet all criteria.

management software, and taking the value 0 otherwise. The following model is estimated:

$$DTuse_i = \beta_0 + \beta_1 X_i + \beta_2 B_i + \beta_3 DTownership_i + \beta_4 Region_i + \epsilon_i, \quad (3)$$

where $DTuse_i$ is a binary dependent variable that indicates whether a firm i uses digital technologies for business purposes. X_i is a vector of entrepreneur-level characteristics, including gender, educational attainment, and motivation to start the business¹⁶. B_i is a vector of firms' basic characteristics, including firm age, the logarithm of monthly profit, access to electricity, number of full-time paid workers, level of informality, sector of activity, and urban location. We add to this vector whether the entrepreneur has a bank account, separates business finances from personal finances, and keeps records, as well as some characteristics of the trading network, such as having formal partners, having businesses as customers, and having partners located further away than the surrounding villages and towns. As the ownership of ICT devices influences the use of digital technologies for business purposes, $DTownership_i$ is a set of dummies that indicate the number of ICT devices the firm possess among mobile phone, computer, and landline phone. $Region_i$ is a set of 82 region dummies controlling for intra- and inter-countries disparities in terms of levels of economic activity and infrastructural connectivity. ϵ_i is an error term clustered at the EA level. Only informal firms are considered in this regression, as being totally formal perfectly predicts the success of the binary outcome¹⁷.

We estimate this model for the whole sample and then for each informal segment, to observe general and segment-specific determinants of digital inequalities. As being located in some regions perfectly predicts the success or failure of the binary outcome, we replace the region dummies with country dummies in the sub-sample regressions.

¹⁶We do not include the age of the entrepreneur due to missing data for all the sample of Rwanda.

¹⁷The 53 firms identified as being totally formal according to the informality index are then excluded from the analysis.

4.3.2 Multivariate decomposition

To further explain the differences in digital technologies usage between the three segments, we use a multivariate decomposition for nonlinear response models (Yun, 2004; Powers et al., 2011), which extends the decomposition technique initially proposed by Oaxaca (1973) and Blinder (1973) to nonlinear models. It allows us to attribute differences in binary outcomes between groups to endowment and coefficient effects. The objective is to decompose segment differences in the probabilities of digital technologies usage into differences in observable characteristics (endowment effect), on the one hand, and differences in the effect that these characteristics have on the outcome of interest (coefficient effect), on the other. Similar analyses have been carried out by Galperin and Arcidiacono (2021) to decompose the gender digital gap in Latin America.

We use the same predictors as in the logit model described above, with a few minor modifications. We replace region effects with country effects, the ICT equipment ownership indicator by its individual components, and the level of informality with two dummies indicating whether the firms are registered and pay taxes, to avoid that these indicators predict success perfectly. Hence, we want to explain the observed differences in digital technologies usage prevalence between segments. Regarding the comparison between the survivalists and the top performers, the assumption is that the second-level digital divide is mainly driven by differences in ownership of ICT devices, human capital and entrepreneurial behavior, and level of economic inclusion (financial inclusion, level of informality, and access to public utilities). In contrast, differences between constrained gazelles and top performers are expected to be mainly explained by differences in the level of economic inclusion and induced differences in firms' characteristics, as they tend to share similar entrepreneur characteristics.

5. Results

5.1 Heterogeneity of micro-sized firms

5.1.1 Partition of microenterprises: the deductive approach

Table 4 reports the estimated coefficients and the corresponding average marginal effects for equation (1), which estimates the probability of being a top performer on a set of predetermined factors.

Women-led firms are less likely to be top performers than men-led firms and joint ventures between men and women. The marginal effect indicates that the probability of being a top performer decreases by 9.5% points for firms managed by a female entrepreneur. This is a similar result that in Grimm et al. (2012) and other studies based on the same classification methodology, that relates to the gender gap in the economic performance of informal firms (Islam and Amin, 2023). The entrepreneur's education level is positively and significantly correlated with being a top performer. Compared to entrepreneurs with no education, primary education increases the probability of being a top performer by 11% points, while secondary and tertiary education increases it by 19% points. The entrepreneurial orientation of the entrepreneur, proxied by his motivation to start the business, is also correlated with top performance. Entrepreneurs who start their activities because they would be unemployed otherwise have a 6% points lower probability of being top performers, the latter being more often opportunity entrepreneurs. The firm's age has a significant and positive effect, as at the margin an increase in the firm's age by one year increases its probability of being a top performer by 0.7% points. However, this effect has a decreasing trend as the quadratic term is negative. This high magnitude is consistent with the fact that we identify top performers based on their level of physical capital stock value. This size criterion relates to the capital accumulation process of the firm, illustrating past performance and probably the firm's age. Similarly, having start capital financed by a formal loan from a microfinance institute

or bank increases the probability of being a top performer by 12% points. We do not observe a significant effect for sectors, potentially due to our inability to disaggregate the sector to a lower level than manufacture, service, and trade. Finally, urban location increases the probability of being a top performer by 5% points, highlighting significant differences between rural firms and urban ones in terms of economic performance.

Table 4: Probability of being a top performer (probit model)

	(1) Coefficients	(2) Marginal effects
Female	-0.371*** (0.055)	-0.095*** (0.014)
No education (Ref.)		
Primary education	0.486*** (0.076)	0.110*** (0.018)
Secondary education	0.738*** (0.092)	0.186*** (0.025)
Tertiary education	0.739*** (0.103)	0.187*** (0.029)
No other opportunity	-0.217*** (0.060)	-0.056*** (0.015)
Age of firm	0.028*** (0.008)	0.007*** (0.002)
Age of firm (squared)	-0.0004** (0.0002)	-0.0001** (0.0001)
Initial capital (Formal loan = 1)	0.482*** (0.125)	0.124*** (0.031)
Manufacturing (Ref.)		
Service	0.051 (0.095)	0.014 (0.026)
Trading	-0.101 (0.079)	-0.026 (0.021)
Urban location	0.196** (0.077)	0.050** (0.020)
Country effects	Yes	Yes
Pseudo-R2	0.082	
Observations	3300	3300

Notes: *p < 0.05, **p < 0.01, ***p < 0.001.

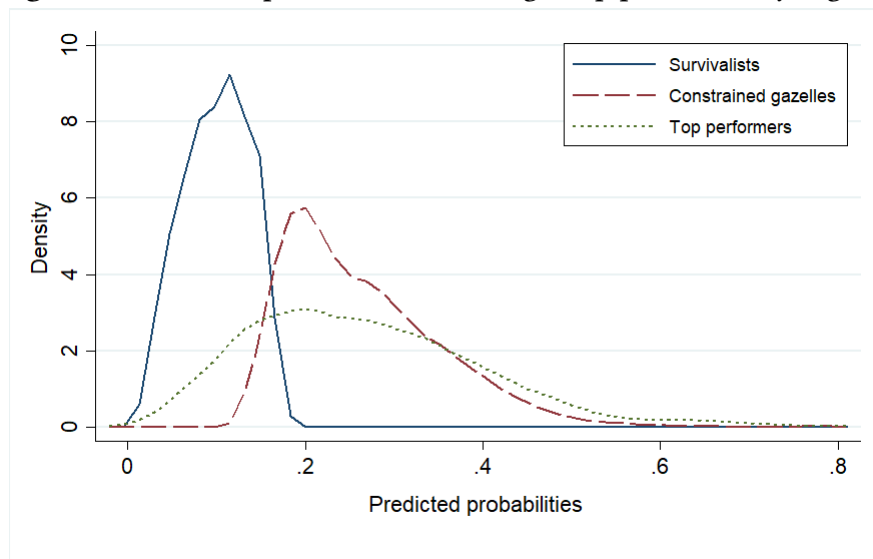
Source: Author's computations based on After Access Surveys, RIA, 2017-2018.

Based on this regression from which we derive the predicted probabilities of being a top performer for each firm, we identify the group of constrained gazelles in sort that its average predicted probabilities are equal to the average in the group of top performers in each country (cf. Section 4.1.2). Table A1 reports the partition into the three informal

sector segments for each of the eight countries. Overall, along the performers, constrained gazelles regroup 40% of the sampled firms and survivalists the same proportion.

We check whether the partition verifies two criteria inherent to the methodology proposed by Grimm et al. (2012). First, by construction, the distribution of predicted probabilities of constrained gazelles should overlap the top performers' distribution, while the survivalists' distribution should be clearly distinct. It assures that, regarding the predetermined factors considered in equation (1), entrepreneurs that we identify as constrained gazelles are on average equally likely to be top performers than the actual top performers. In Figure 1, we report the kernel densities of predicted probabilities of being a top performer for each segment. We observe that kernel densities of constrained gazelles and top performers overlap, while the predicted probabilities of survivalists are concentrated at the low values, as expected. However, even among top performers, some firms have low predicted probabilities, confirming the limited predictive power of the probit model while only considering predetermined regressors.

Figure 1: Predicted probabilities of being a top performer by segment



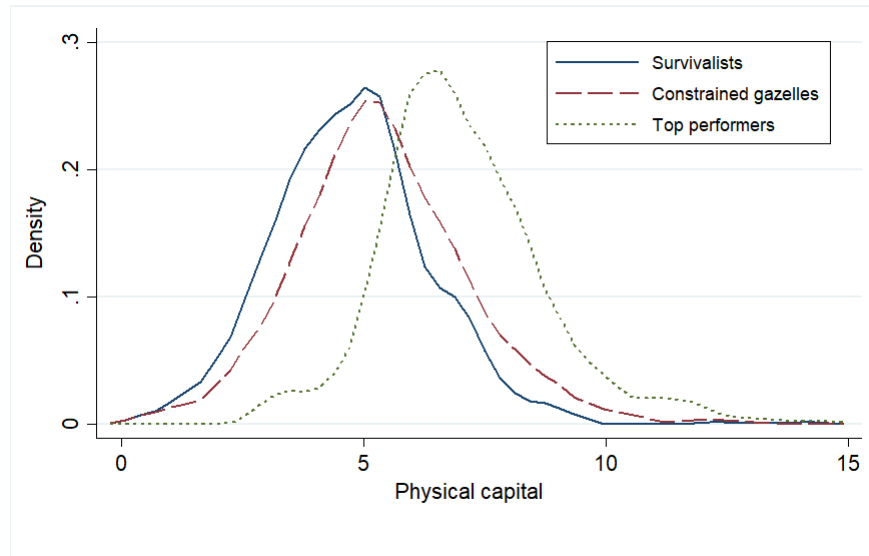
Source: Author's computations based on After Access Surveys, RIA, 2017-2018.

Second, constrained gazelles should have a similar distribution to survivalists in terms of physical capital stock and net profit, the two selected criteria used to identify top performers. The kernel densities of the two distributions¹⁸ for each segment verify this

¹⁸Null values of capital stock or profit are not included in these graphical distributions.

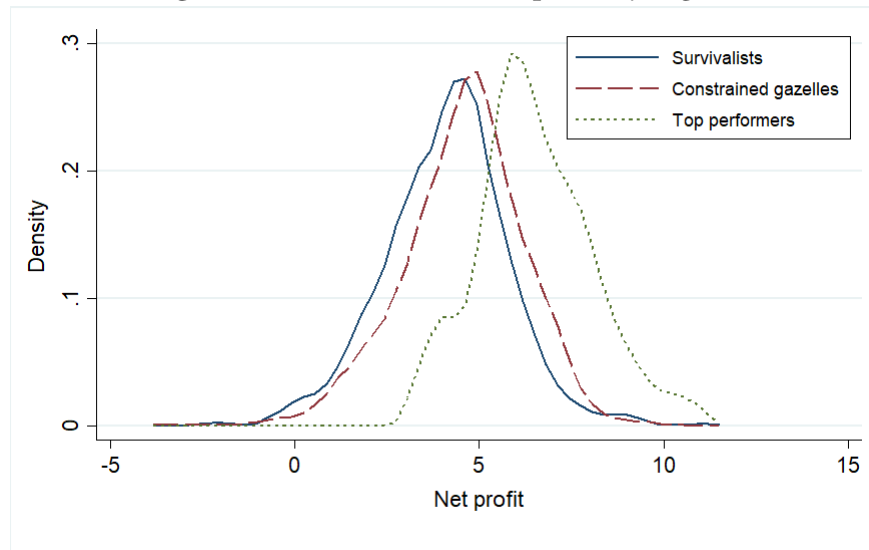
condition, although the distributions of constrained gazelles are slightly more on the right than the ones of survivalists (Figures 2 and 3). It confirms that although constrained gazelles are, on average, equally likely to be top performers than the actual ones, they share similar levels of capital accumulation and economic performance to the lower tier of survivalists.

Figure 2: Distribution of physical capital by segment



Source: Author's computations based on After Access Surveys, RIA, 2017-2018.

Figure 3: Distribution of net profit by segment



Source: Author's computations based on After Access Surveys, RIA, 2017-2018.

5.1.2 Segmentation and degree of informality

In Table 5, we present the distribution between the partition into the three segments and the levels of informality identified based on a five criteria informality index¹⁹²⁰. Overall, the index reveals that the majority of the surveyed firms (54%) operate completely informally, i.e., without any registration with the authorities, payment of taxes, or formal accounts. Conversely, only 2% meet all the formality criteria, making them formal firms. Furthermore, 29% of the surveyed firms operate at a high level of informality, complying with only one or two of the criteria, while 16% operate at a low level of informality, complying with 3 or 4 of the criteria. A strong correlation stands out between the segmentation and the levels of informality. Most survivalists (68%) are totally informal, confirming their high level of vulnerability. Conversely, top performers are only 30% in this case, highlighting that higher economic performances are associated with a lower level of informality. About 5% of top performers are even formal, regrouping the two tiers of formal firms in the sample. Constrained gazelles are in an intermediate position, with half of them operating completely informally.

Table 5: Distribution of firms according to the level of informality (%)

	(1) Survivalists	(2) Constrained gazelles	(3) Top performers	(4) All
Totally formal	0.1	1.2	5.5	1.6
Low level of informality	8.3	16.2	28.8	15.6
High level of informality	23.2	35.4	31.4	28.9
Totally informal	68.4	51.2	30.4	53.9

Notes: Totally informal firms meet zero criteria, high informal firms meet one or two criteria, low informal firms meet three or four criteria, and formal firms meet all criteria.

Source: Author's computations based on After Access Surveys, RIA, 2017-2018.

¹⁹The five criteria are: (1) being registered with a local authority or municipality, (2) being registered at general registrar, (3) paying local or municipal taxes (tax stamps), (4) being registered for national VAT or sales tax, and (5) keeping accounts according to national or regional standards.

²⁰Distribution of firms by score is presented in Table A2.

5.1.3 Robustness check: deductive versus inductive approach

Finally, we test the robustness of our segmentation by comparing it with that resulting from a Hierarchical Clustering on Principal Components (HCPC) computed on a large set of entrepreneurs' and firms' characteristics. The partition in three clusters reveals an upper tier of firms (25%) corresponding to our segment of top performers, another lower tier of firms (45%) corresponding to our segment of survivalists, and an intermediate segment (30%) corresponding to our segment of constrained gazelles.

Globally, it appears that the correlation between our main segmentation and the alternative measure is relatively high, as the classifications, although based on significantly different methodology and variables, assign the same segment to 63% of the sampled firms. Table 6 reports the transition matrix for firms between the two segmentations computing by the deductive and inductive approaches. It shows that 84% of top performers are also assigned to the upper tier cluster, demonstrating that our identification of the most successful firms is quite robust to the methodology used²¹. Our identification of survivalists is also robust, as 70% of them are identified in the lower tier of firms by the cluster analysis.

For the constrained gazelles, we observe less correspondence between the two partitions (45%). It is probably due to the specific definition of constrained gazelles in the methodology proposed by Grimm et al. (2012), which aims to identify a group of entrepreneurs with similar entrepreneur characteristics with top performers but displaying low capital accumulation and economic performance as survivalists. In this sense, our main segmentation identifies constrained gazelles according to their potential to become top performers based on a set of predetermined factors. Conversely, the cluster analysis identifies an intermediate segment with specific observable characteristics clearly distinct from other clusters. Then, the fact that 39% of our constrained gazelles are assigned to the lower tier of firms in the cluster analysis is logical, as the latter observes the actual performance of firms to classify them and not their predicted economic potential.

²¹The proportion of top performers identified by the cluster analysis (25%) confirms the pertinence of our choice to identify 20% of top performers in the deductive approach instead of only 10%.

Table 6: Transition matrix between deductive and inductive segmentation (%)

Robustness test - Inductive approach	Main segmentation - deductive approach			Total
	Survivalists	Constrained gazelles	Top performers	
Lower tier	69.8	39	7.3	44.9
Intermediate tier	25.2	44.9	9	29.9
Upper tier	5	16.1	83.7	25.2
Total	39.8	40.3	20	100

Notes: Column percentages are reported.

Source: Author's computations based on After Access Surveys, RIA, 2017-2018.

5.2 Differences in the characteristics of firms and entrepreneurs across segments

Table 7 presents the characteristics of entrepreneurs and firms in the three segments identified. Above all, the three groups differ in their economic performance, with top performers being effectively the most successful businesses. Their average monthly sales are more than six times higher than those of the survivalists and constrained gazelles. This gap widens further with value-added and net profit, with the average values of the top performers being eight times higher than those of the other segments. These observations are consistent with significant differences in firm size. While a significant proportion of survivalists (42%) and constrained gazelles (40%) do not own any physical assets of value, top performers are by far the most capital-intensive segment. These differences are a mechanical consequence of the method used to identify the top performers, which considers the stock of physical capital as a size criterion and net profit as a performance criterion.

As we identify constrained gazelles based on a set of predetermined factors, they share similar sector occupation and socio-demographic characteristics with top performers. Indeed, they are more represented in the manufacturing and service sectors than the survivalists. Findings also show that only 29% of top performers and constrained gazelles are exclusively run by women, while this figure rises to 62% among survivalists. This is in line with previous literature that found that women are underrepresented among top

Table 7: Comparison of groups by firm and entrepreneur characteristics

	(1)	(2)	(3)	(4)	(5)
	Survivalists	Constrained gazelles	Top performers	t-Test (1) vs. (2)	t-Test (2) vs. (3)
Entrepreneur characteristics					
Man	0.35	0.61	0.59	0***	0.429
Woman ^b	0.62	0.29	0.29	0***	0.923
Joint venture	0.03	0.10	0.12	0***	0.157
Age	38.1	38.1	38.2	0.852	0.939
No education ^b	0.66	0.13	0.20	0***	0***
Primary education ^b	0.25	0.38	0.34	0***	0.147
Secondary education ^b	0.07	0.29	0.27	0***	0.365
Tertiary education ^b	0.02	0.20	0.18	0***	0.315
No other opportunity ^b	0.67	0.38	0.39	0***	0.596
Firm economic performance					
Sales	1066	1205	8187	0.591	0***
Value-added	782	558	4727	0.519	0***
Net profit ^a	343	316	2558	0.736	0***
Firm characteristics					
# of full-time paid workers	1.5	2.1	2.9	0***	0***
Any full-time paid worker	0.73	0.59	0.49	0***	0***
Physical capital ^a	1354	1254	12471	0.922	0***
No capital	0.42	0.40	0	0.304	0***
Formal loan as initial capital ^b	0.01	0.05	0.07	0***	0.064*
Urban ^b	0.48	0.74	0.72	0***	0.372
Manufacture ^b	0.10	0.14	0.14	0.004***	0.944
Service ^b	0.10	0.25	0.26	0***	0.565
Trade ^b	0.80	0.61	0.60	0***	0.642
Age of firm ^b	5.8	7.8	8.1	0***	0.464
Access to electricity	0.46	0.64	0.83	0***	0***
Registration (local level)	0.21	0.33	0.55	0***	0***
Registration (national level)	0.06	0.14	0.26	0***	0***
Taxes payment (local level)	0.27	0.43	0.63	0***	0***
Taxes payment (national level)	0.25	0.42	0.60	0***	0***
Keep accounts	0.36	0.51	0.66	0***	0***
Separate finance	0.24	0.42	0.54	0***	0***
Bank account	0.14	0.27	0.46	0***	0***
Trading network's characteristics					
Any supplier	0.21	0.21	0.12	0.717	0***
One supplier	0.31	0.27	0.18	0.007***	0***
Two or three suppliers	0.32	0.33	0.40	0.309	0.002***
More than three suppliers	0.16	0.19	0.29	0.018**	0***
Formal suppliers	0.42	0.53	0.69	0***	0***
Businesses as customers	0.13	0.20	0.35	0***	0***
Not locally located trading partners	0.06	0.11	0.22	0***	0***
Very reliable suppliers	0.15	0.20	0.27	0.001***	0.001***
Relational contracting	0.48	0.50	0.56	0.177	0.018**
Long relationship	0.29	0.44	0.49	0***	0.015**
Weekly contact with suppliers	0.47	0.50	0.57	0.088*	0.004***
N	1312	1329	659		

Notes: *p < 0.05, **p < 0.01, ***p < 0.001.

^a Variables used to identify top performers. ^b Variables used to identify constrained gazelles. All monetary values are expressed in 2017 Intl.\$ PPP.

Source: Author's computations based on After Access Surveys, RIA, 2017-2018.

performers (Grimm et al., 2012). Two tiers of survivalists have no education compared to a minority of top performers and constrained gazelles, which is consistent with the

exclusion from the formal labor market traditionally attributed to survivalists. Indeed, findings confirm that the survivalists are entrepreneurs by necessity, as 67% declare that they started their activity because they would have been unemployed otherwise. However, a significant proportion of top performers and constrained gazelles also make this claim, highlighting the importance of entrepreneurship in earning a living in sub-Saharan Africa.

Table 7 shows other characteristics of each segment that we have not used in the segmentation approach. Structural business characteristics are consistent with these performance and capital accumulation disparities. The majority of the survivalists (73%) and constrained gazelles (59%) are self-employed workers as they do not employ any full-time paid workers other than the owner. In contrast, the top performers are more likely to be employers with at least one additional full-time paid worker, but still exhibit a high proportion of self-employed workers (49%). Moreover, the most successful firms are also the oldest and those with the highest access to public utilities. Indeed, almost all top performers (83%) have access to electricity, while only 46% of survivalists and 64% of the constrained gazelles benefit from it. This difference in access to utilities probably illustrates significant disparities in operating conditions, with survivalists mainly conducting petty trading activities in markets or in precarious premises, while the top performers, and to a lesser extent the constrained gazelles, may be better established²².

Therefore, the three segments regroup entrepreneurs with different socio-demographic characteristics and structurally different businesses. It is reflected in different entrepreneurial behavior, particularly in how they conduct their business and comply with regulations. Top performers keep financial records more often than others, even if this is just simple bookkeeping. This management behavior is often accompanied by the strict separation of business accounts from personal finances. Moreover, as described above, the level of informality at which entrepreneurs in each segment conduct their business is also a meaningful distinction. Over half of the top performers are registered with local or national authorities, and almost two-thirds are subject to taxation. These

²²The available data does not provide additional information about the premises and operating conditions of the businesses that would help clarify this point.

differences in the level of informality are also correlated with the level of access to banking services. Almost half of the top performers have a bank account, while only 14% and 27% of the survivalists and constrained gazelles have one, respectively.

Finally, the characteristics of firms' trading network differ in each segment. Top performers integrate more complex value chains than the survivalists, who are limited to retailing locally supplied goods to nearby inhabitants. In addition to having locally based suppliers, the top performers also buy their goods and raw materials more often from suppliers further away geographically. The legal status of the suppliers with whom businesses deal also varies by segment. More than two-thirds of the top performers deal with formal businesses as suppliers, compared to 42% for survivalists and 53% for constrained gazelles. Almost all the firms in the sample have households as customers. However, the top performers and constrained gazelles are more involved in business-to-business relationships than survivalists. Although the main customers of the businesses are located in the neighborhood, whatever the segment, the top performers are more concerned with exports.

5.3 Informal heterogeneity and digital technologies

Table 8 reports access to and use of digital technologies by segment. Descriptive statistics suggest significant access inequalities. While only 8% of top performers do not own a device, 18% of constrained gazelles and 31% of survivalists do not have access to digital technologies. We observe these access inequalities for all the devices considered, with top performers being the segment with the highest mobile phone, landline phone, and computer ownership rates. Constrained gazelles are almost as well equipped as the top performers regarding mobile phones, the most widespread equipment. The possession of other devices mainly concerns these two segments, with very few survivalists owning a landline phone or a computer. Thus, inequalities in access mainly affect survivalists, although constrained gazelles demonstrate lower access to digital technologies than top performers.

Table 8: Comparison of segments by DT equipment and usage

	(1)	(2)	(3)	(4)	(5)
	Survivalists	Constrained gazelles	Top performers	t-Test (1) vs. (2)	t-Test (2) vs. (3)
Ownership of DT devices					
Mobile phone	0.69	0.82	0.91	0***	0***
Landline	0.01	0.04	0.09	0***	0***
Computer	0.01	0.06	0.16	0***	0***
Number of DT devices owned					
Any	0.31	0.18	0.08	0***	0***
One	0.68	0.76	0.75	0***	0.721
Two	0.02	0.05	0.11	0***	0***
Three	0	0.02	0.06	0***	0***
Second-level digital divide					
DT users	0.49	0.69	0.85	0***	0***
Number of functions used ^a	2.12	2.42	3.03	0***	0***
DT for external coordination					
Bilateral coordination with suppliers	0.36	0.49	0.66	0***	0***
Bilateral coordination with customers	0.33	0.50	0.65	0***	0***
Multilateral coordination	0.06	0.13	0.25	0***	0***
DT for financial transactions					
Online or mobile banking	0.04	0.09	0.20	0***	0***
Mobile money to send money	0.13	0.24	0.36	0***	0***
Mobile money to receive money	0.13	0.21	0.36	0***	0***
DT for internal management					
Use of software	0	0.02	0.09	0***	0***
N	1312	1329	659		

Notes: ^a The average number of functions implemented by firms that use at least one function of digital technologies. *p < 0.05, **p < 0.01, ***p < 0.001.

Source: Author's computations based on After Access Surveys, RIA, 2017-2018.

Looking at the second-level digital divide, survivalists remain the most digitally excluded since only 49% of them use digital technologies for at least one of the functions defined above. These professional practices are much more widespread among constrained gazelles (69%) and top performers (85%). These disparities in usage rates are likely to be explained by differences in ownership rates. However, the transition from access to actual usage appears not equally important for each segment. Indeed, while 86% of top performers owning an ICT device use it for business purposes, this figure drops to 76% among constrained gazelles and falls to 58% for survivalists. Furthermore, digital inequalities persist within the user group, as top performers exhibit a greater diversity of use compared to the other segments. On average, top performers using digital technologies implement three functions compared to two functions for the other segments.

Disparities in usage exist between the different segments for each function of the digital technologies considered. Using these technologies for bilateral coordination with suppliers or customers is almost ubiquitous among top performers, with 79% engaging in such behavior. While constrained gazelles also broadly use this type of function (64%), this is not the case for survivalists, whose use of bilateral coordination is less widespread (44%). The use of social media or the internet in general for multilateral coordination purposes concerns few firms, with only one-quarter of top performers and 13% of constrained gazelles doing so. These advanced practices, such as online advertising, selling products and services online, or searching for information, are employed by only 6% of survivalists. The use of digital technologies for financial transactions through mobile money or online banking services is also less widespread among survivalists. Only 17% of them receive or send money via mobile money for business purposes, compared to 29% and 43% among constrained gazelles and top performers, respectively. While top performers are already the most likely to have a bank account, they also benefit the most from financial technology innovations. In addition, the few users of software for inventory management, accounting, or performance monitoring are mostly top performers (68%).

5.4 Digital divides among informal firms

5.4.1 Determinants of professional usage of digital technologies

Table 9 reports the results of the multivariate analysis, which estimates the probability of digital technologies usage for business purposes on observable entrepreneurs' and firms' characteristics in the eight African countries. In this table, we show the average marginal effects²³, which display the average change in predicted probabilities if the explaining variable is changed by one unit. Column 1 presents the average marginal effects estimated for the whole sample.

²³Table A3 presents the underlying estimated coefficients.

Table 9: Determinants of digital technologies usage for business purposes

	(1)	(2)	(3)	(4)
	All	Survivalists	Constrained gazelles	Top performers
Gender of the owner (ref. Man)				
Woman	-0.067*** (0.016)	-0.010*** (0.029)	-0.031 (0.026)	0.002 (0.032)
Both	0.005 (0.029)	-0.068 (0.073)	0.035 (0.039)	0.024 (0.058)
Education of owner (ref. None)				
Primary	0.035* (0.019)	0.056 (0.035)	0.108*** (0.037)	0.015 (0.031)
Secondary	0.060** (0.024)	0.135** (0.057)	0.089* (0.047)	0.021 (0.053)
Tertiary: Diploma /Certificate	-0.012 (0.028)	-0.076 (0.081)	0.030 (0.047)	0.024 (0.058)
Age of the firm	0.002 (0.001)	-0.002 (0.003)	0.003 (0.003)	0.007* (0.004)
Age of the firm (squared)	-2.48e-05 (1.79e-05)	2.75e-05 (4.01e-05)	2.54e-05 (7.65e-05)	-0.000136** (6.13e-05)
Log monthly profits	0.019*** (0.005)	0.014 (0.010)	0.019** (0.008)	0.001 (0.017)
Number of full-time paid workers (Ref. None)				
1 or 2 full time workers	0.023 (0.020)	0.040 (0.031)	0.033 (0.030)	0.025 (0.033)
3 or more full time workers	0.059* (0.033)	0.004 (0.062)	0.091* (0.051)	0.076 (0.058)
Sector of activity (Ref. Manufacture)				
Service	-0.038 (0.024)	-0.004 (0.052)	-0.063* (0.033)	-0.060 (0.040)
Selling/Trading	-0.097*** (0.020)	-0.060 (0.040)	-0.119*** (0.032)	-0.143*** (0.030)
Urban location	0.016 (0.017)	-0.007 (0.028)	-0.002 (0.028)	0.015 (0.028)
Level of informality (Ref. Low level)				
High level of informality	0.044 (0.028)	0.136** (0.053)	-0.064 (0.043)	0.117*** (0.039)
Totally informal	-0.056** (0.028)	0.014 (0.051)	-0.155*** (0.043)	0.063 (0.042)
Access to electricity	0.054*** (0.016)	0.073** (0.029)	0.059*** (0.023)	0.037 (0.035)
Bank account	0.093*** (0.022)	0.070** (0.035)	0.094*** (0.029)	0.070** (0.030)
Not keeping accounts	-0.068*** (0.020)	-0.078** (0.034)	-0.039 (0.024)	-0.062** (0.029)
Separate finance	-0.024 (0.016)	0.008 (0.031)	-0.019 (0.023)	-0.015 (0.030)
No other opportunity	-0.038*** (0.015)	-0.026 (0.029)	-0.062*** (0.023)	-0.018 (0.025)
B2B relations	0.096*** (0.023)	0.141*** (0.039)	0.062* (0.036)	0.070* (0.039)

(continued on next page)

	(1)	(2)	(3)	(4)
	All	Survivalists	Constrained gazelles	Top performers
Formal partners	0.062*** (0.015)	0.058** (0.024)	0.063*** (0.024)	0.049* (0.028)
Not local trading partners	0.110*** (0.033)	0.280*** (0.072)	0.064 (0.048)	0.098** (0.045)
Number of ICT devices owned (Ref. Zero)				
1	0.168*** (0.021)	0.148*** (0.028)	0.228*** (0.034)	0.071 (0.053)
2	0.290*** (0.042)	0.312*** (0.114)	0.321*** (0.058)	0.155** (0.062)
3	0.397*** (0.082)	-	0.392*** (0.076)	-
Region effects	Yes	No	No	No
Country effects	No	Yes	Yes	Yes
Observations	3191	1287	1297	601

Notes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Robust standard errors are in parentheses.

Source: Author's computations based on After Access Surveys, RIA, 2017-2018.

The results indicate that certain socio-demographic characteristics of entrepreneurs are associated with the usage of digital technologies for business purposes. In line with previous research, our findings show that firms led by women are 6.7% points less likely than firms led by men to use at least one function of digital technologies for business purposes. Education attainment is a significant driver too, as primary and secondary education increase the probability of using digital technologies for business purposes by 3.5% and 6% compared to entrepreneurs with no education. Although most entrepreneurs with tertiary education use digital technologies, no significant differences appear between them and entrepreneurs with no educational attainment after controlling for other entrepreneur and firm characteristics. No significant association is found between the digitalization of firms' business operations and urban location, which may be explained by the fact that the model includes region effects to control for cross-region disparities in terms of digital connectivity and urbanization rate, for example. All these findings show that some socio-demographic determinants of the digital divide usually identified in sub-Saharan Africa at the individual level, such as gender and education attainment, persist in the productive sphere and the sub-population of informal entrepreneurs²⁴. Beyond

²⁴We do not include the age of the entrepreneur in the model due to missing data for all observations in Rwanda. However, when estimating this model for the whole sample without Rwanda, a negative

the fact that it indicates that personal and professional uses of digital technologies are intrinsically linked, it invites us to deepen our understanding of the digital divide at the firm-level by exploring the role of entrepreneurial attributes and firm characteristics.

In line with findings in the existing literature regarding the role of household income, our results reveal a positive correlation between monthly profits and the use of digital technologies. Although the relation is endogenous, as the adoption of digital technologies may enhance firms' economic outcomes, it highlights that successful firms may have a greater ability to pay for digital devices and services, and a greater need and willingness to use them. Additionally, we observe a significant association between the use of digital technologies and firm size, as firms with three or more full-time paid workers are more likely to incorporate digital technologies in their business operations than self-employed entrepreneurs. Access to electricity also appears to increase the probability of using digital technologies for business purposes by 5.4% points, confirming the importance of access to utilities and the quality of business premises.

Older firms are not associated with a higher probability of usage, while trade activities are less associated with digital technologies usage than manufacturing activities (-9.7% points). These results highlight some sectoral specificities, as the nature of the economic activity probably shapes the professional use of digital technologies due to specific organizational modes, business relationships, and sales channels. Indeed, the characteristics of trading partners appear to influence the second-level digital divide at the firm-level. Firms with formal suppliers have a 6.2% point higher likelihood of using digital technologies. Similarly, having businesses as customers increases the estimated probability by 9.6% points. These results indicate potential network effects in the diffusion of digital technologies, as having formal suppliers and expanding customer base to other businesses may create a greater need to adopt these technologies. Moreover, having business partners located further away than the surrounding villages or towns increases the likelihood of using digital technologies by 11% points.

association is found between the age of the entrepreneur and the use of digital technologies, as entrepreneurs over 40 years old are significantly less likely to use these technologies than younger ones (15-30 years old).

Entrepreneurial behavior also plays a significant role in the second-level digital divide among informal firms in sub-Saharan Africa. We find that opportunity entrepreneurs are more likely to use digital technologies for business purposes than others. Indeed, entrepreneurs who indicate that they started their businesses due to a lack of other employment opportunities are 3.8% points less likely to use digital technologies. While there is no significant association with the strict separation of business accounts from personal finances, the absence of record-keeping decreases the probability of using digital technologies by 6.8% points. Furthermore, financial inclusion is a significant determinant of the second-level digital divide among informal firms. Having a bank account is significantly correlated with a higher likelihood of using these technologies, with an increase of 9.3% points. Finally, the degree of informality remains a major factor in digital inclusion. In comparison to firms with a low level of informality, totally informal firms are 5.6% points less likely to use digital technologies for business purposes.

Estimations are controlled by the number of devices that firms possess. As expected, material access is strongly correlated with using such technologies, confirming the sequential process of the digital divide. Furthermore, it appears that the cumulative possession of devices is strongly associated with being a user. In comparison to firms with no ownership of ICT devices, the probability of using digital technologies increases by 16.8% points when owning just one device, by 29% points with ownership of two devices, and by 39.7% points when owning a mobile phone, a landline phone, and a computer.

Within each segment, we observe specific patterns in the second-level digital divide, along with shared factors (Table 9, columns 2, 3, and 4). Common factors influencing digital technologies adoption include the number of ICT devices owned, the access to a bank account, and the characteristics of firms' trading network. It confirms the importance of material access in bridging the second-level digital divide among informal firms, but also demonstrates the importance of financial inclusion and network effects in facilitating their adoption of digital technologies. In contrast, socio-demographic traits of entrepreneurs are not associated with the second-level digital divide among top performers, these characteristics being only significant drivers among the most

vulnerable informal segments. While the educational level is significant for both constrained gazelles and survivalists, the gender gap in the use of digital technologies for business purposes is only significant for survivalists. Access to electricity appears to be a significant determinant only among survivalists and constrained gazelles, which probably face higher external constraints than top performers. Other structural characteristics of the firm are involved in the second-level digital divide for constrained gazelles and top performers. Sector specificities appear for both, while the firm size and profit level are significant only for constrained gazelles, and firm age is significant only for top performers. Finally, not keeping accounts decreases the probability of being a digital technology user only for survivalists and top performers.

5.4.2 Decomposition analysis of usage gaps between informal segments

To further analyze the disparities in digital technologies usage between the three segments, we perform a multivariate decomposition for nonlinear response models (Yun, 2004; Powers et al., 2011). Table 10 reports the detailed decomposition results comparing survivalists with top performers (column 1), and constrained gazelles with top performers (column 2). The decomposition aims to explain the sources of the observed disparities in usage rates across segments, that is 36% points between top performers and survivalists, and 16% points between top performers and constrained gazelles. These disparities can be attributed to endowment and coefficient components, and within these components, to specific factors.

In the first column, we find that the difference in the use of digital technologies between survivalists and top performers is mainly due to endowment effects (85%), i.e., differences in the characteristics of firms and entrepreneurs²⁵. Despite the significant disparities in material access between the two segments, shifting the survivalist's distribution of mobile phone and computer ownership to top performers levels would be expected to reduce the usage gap by only 11%. Thus, while addressing material access inequalities

²⁵As the coefficient effects explain only about 15% of the usage gap, we restrain the interpretation of the decomposition results to the endowment effects. Results of the coefficient effects decomposition are available upon request.

is important, it may not be sufficient to bridge the second-level digital divide between subsistence entrepreneurs and top performers. Indeed, the usage gap is destined to persist given the disparities in terms of skills and motivation between firms in the two segments. The endowment effects associated with secondary education and bookkeeping emphasize that internal constraints associated with entrepreneurial skills explain the second-level digital divide between top performers and survivalists as much as material access disparities (11%). Similarly, survivalists appear to be constrained by their low level of economic inclusion. Shifting the survivalist's distributions of bank account ownership, level of informality, and electricity access to top performers levels would decrease the second-level digital divide between the two segments by 19%. In addition, the firm's trading network characteristics appear to explain a large part of usage disparities (21%). Given that informal firms mostly use digital technologies for bilateral coordination with trading partners, it may indicate that subsistence entrepreneurs face weaker pull factors to use digital technologies for business purposes, as their trading network's structure may generate lower network effects. Finally, a non-negligible part of the disparities in usage between subsistence entrepreneurs and top performers is driven by more general gender inequalities (8%).

Column 2 shows that the usage gap between constrained gazelles and top performers is also largely explained by endowment effects (87%). Disparities in economic inclusion account for a significant portion of the observed difference in digital technologies usage between these two segments, with the level of informality, access to electricity, and access to a bank account remaining important factors. Indeed, bringing the distribution of these variables for constrained gazelles up to the level of the top performers' distributions would reduce the usage gap between the two segments by about 34%. Furthermore, equalizing the profit levels of constrained gazelles to those of top performers is expected to reduce the usage gap by about 21%. The first-level digital divide also contributes to the usage disparities, with mobile phone (11%) and computer ownership (5%) playing significant roles in the endowment effect. It highlights that, more than for survivalists, material access and affordability of digital technology services are key factors in the usage

inequalities between the constrained gazelles and the top performers. This is further supported by the fact that entrepreneurial attributes do not appear to play a significant role in these usage disparities between the two segments, as constrained gazelles and top performers share similar socio-demographic characteristics and entrepreneurial behavior. Finally, the characteristics of their trading networks remain significant drivers in the endowment component (11%), but to a lesser extent than for survivalists (21%).

Table 10: Decomposition of the usage gap between top performers and other segments

	(1) Survivalists vs. Top performers (%)	(2) Constrained gazelles vs. Top performers (%)
Prevalence of DT usage		
Top performers	85.0	85.0
Survivalists / Constrained gazelles	49.3	69.4
Difference (in % points)	35.7	15.6
Difference in characteristics	85.2	86.6
Women	7.9***	-0.1
No education	2.9	-2.5**
Primary education	0.8	-0.8***
Secondary education	4.9***	-0.7
Tertiary education	-4.4**	-0.3
Age of firm	-1.4	0.3
Monthly profits (log)	8.2	21.4***
Any paid workers	0.5	2.6
1 or 2 paid workers	0.5	0
3 or more paid workers	-0.4	2.9**
Manufacturing sector	0.2	-0.2***
Service sector	0.7	0
Trade/retail sector	2.1**	0
Urban	-0.6	0
Registration	2.5	7.0*
Payment of taxes	7.1**	9.6***
Electricity	6.8***	6.9***
Bank account	5.4**	10.1***
No opportunity	1.8	-0.9***
Separate finance	0.8	-1.2
Bookkeeping	5.7***	3.0
Businesses as customers	7.3***	5.1*
Formal suppliers	3.8**	5.7***
Not local partners	9.7***	3.5
Mobile phone	8.1***	10.8***
Computer	2.6	5.3*
Number of observations	1934	1936

Notes: *p < 0.05, **p < 0.01, ***p < 0.001. Coefficients of country dummies and the square of firm age are not presented.

Source: Author's computations based on After Access Surveys, RIA, 2017-2018.

6. Conclusion

Major and ongoing investments in telecommunication infrastructures have greatly contributed to the diffusion of digital technologies in developing countries. However, despite similar network coverage, intra-country disparities persist in terms of material access and usage patterns. While these digital inequalities, or digital divides, between households or individuals have been largely studied, there is little evidence at the firm-level in sub-Saharan Africa. Given that digital technologies have great potential to increase the performance of informal businesses by addressing market and state failures, identifying the determinants of digital inequalities among informal firms seems to be of prior importance.

In this chapter, we analyze the digital inclusion of informal firms from eight sub-Saharan African countries, considering the diversity of devices and functions offered by digital technologies, and the heterogeneous nature of informal activities. Our findings suggest that informal entrepreneurs widely own mobile phones and use digital technologies for business purposes. However, they mainly rely on digital technologies for bilateral coordination with their suppliers and customers, with the appropriation of more advanced usage, such as the internet, mobile money, and management software, still in their early stages. In addition to significant disparities across countries, our findings reveal the existence of substantial digital inequalities between informal firms, that align with the vertical heterogeneity of informal sectors in sub-Saharan Africa. The lower tier of survivalists is the most digitally excluded regarding ICT device ownership and professional usage. Conversely, the most successful firms, the so-called top performers, largely embrace digital technologies in their way of doing business. Despite being almost as well equipped and having similar socio-demographic characteristics and entrepreneurial behaviors as top performers, firms in the intermediate segment still exhibit a lower level of digital technologies usage than the most successful firms. Findings show that the disparities in the use of digital technologies by gender and educational attainment observed at the individual level persist in the productive sphere. At the

same time, firms with a high level of informality, low profits, precarious operating conditions, no access to financial services, and less developed value chains are less likely to use digital technologies. Addressing digital inequalities appears to have common and segment-specific levers. The decomposition results show that subsistence entrepreneurs face significant barriers in the successive phases of digital technologies appropriation. These barriers include motivation, material access, skills, and the affordability of digital services. Conversely, the usage gap between constrained gazelles and top performers is largely driven by differences in their ability to afford digital services. While differences in material access and motivation also contribute to the usage gap between these two segments, internal constraints, such as entrepreneurial skills, do not seem to play a significant role.

Hence, despite the benefits attributed to the adoption of digital technologies by businesses, their uneven spread risks exacerbating inequalities rather than creating new opportunities for inclusion for all. Indeed, this new technological dimension adds to the sources of exclusion already experienced by subsistence entrepreneurs, and is likely to dig the gap between the most successful entrepreneurs and those in the intermediate segment. Bridging the second-level digital divide in informal sectors of sub-Saharan Africa requires considering their heterogeneity, as entrepreneurs may face different combinations and magnitude of constraints in their professional appropriation of digital technologies. If material access is a prior condition for usage, policy intervention should focus on other important digital inequalities drivers. Indeed, access to mobile phones is almost ubiquitous, but the second-level digital divide remains significant in terms of professional appropriation of digital technologies, diversity of functions used, and probably intensity of usage between segments of informal entrepreneurs. Our findings show that constrained gazelles face mainly external constraints, especially the lack of affordability of digital services, in their professional appropriation of digital technologies. Individual or internal constraints, such as education, entrepreneurial skills, and motivation to adopt these new technologies, are not the most binding constraints for this segment of entrepreneurs with untapped potential. In contrast, survivalists also lack

these internal capacities and are constrained by external factors. In this segment, we find that a gender digital divide persists, with female survivalists being less likely to use digital technologies, possibly because of cumulative socio-cultural norms that are unfavorable to women. In addition, digital inequalities across segments of informal entrepreneurs could be partially explained by disparities in digital skills, but the limited data does not allow us to explore this important dimension of access. Our results suggest that policy interventions should consider the heterogeneity of informal sectors, as addressing digital inequalities appears to have common and segment-specific levers.

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Appendix

Table A1: Distribution across segments by country

	South Africa	Nigeria	Ghana	Kenya	Senegal	Tanzania	Rwanda	Mozambique
Survivalists	0.38	0.39	0.46	0.27	0.41	0.44	0.45	0.36
Constrained gazelles	0.42	0.41	0.34	0.53	0.39	0.36	0.35	0.44
Top performers	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20

Source: Author's computations based on After Access Surveys, RIA, 2017-2018.

Table A2: Distribution of firms according to their informality index score

	(1)	(2)	(3)	(4)
Score	Survivalists	Constrained gazelles	Top performers	All
5	0.001	0.01	0.05	0.02
4	0.03	0.08	0.14	0.07
3	0.05	0.08	0.14	0.08
2	0.11	0.16	0.21	0.15
1	0.12	0.16	0.15	0.14
0	0.68	0.51	0.30	0.54

Notes: The five criteria are: (1) being registered with a local authority or municipality, (2) being registered at general registrar, (3) paying local or municipal taxes (tax stamps), (4) being registered for national VAT or sales tax, and (5) keeping accounts according to national or regional standards.

Source: Author's computations based on After Access Surveys, RIA, 2017-2018.

Table A3: Determinants of digital technologies usage for business purposes

	(1)	(2)	(3)	(4)
	All	Survivalists	Constrained gazelles	Top performers
Gender of owner (ref. Man)				
Woman	-0.497*** (0.122)	-0.615*** (0.178)	-0.233 (0.195)	0.0217 (0.340)
Both	0.0391 (0.228)	-0.419 (0.447)	0.275 (0.314)	0.269 (0.671)
Education of owner (ref. None)				
Primary	0.259* (0.140)	0.345 (0.218)	0.802*** (0.260)	0.153 (0.314)
Secondary	0.451** (0.182)	0.835** (0.353)	0.652* (0.340)	0.217 (0.564)
Tertiary: Diploma /Certificate	-0.0891 (0.207)	-0.483 (0.533)	0.216 (0.335)	0.254 (0.617)
No other opportunity	-0.292*** (0.112)	-0.163 (0.183)	-0.480*** (0.175)	-0.197 (0.270)
Age of the firm	0.0111 (0.0104)	-0.0141 (0.0173)	0.0194 (0.0243)	0.0734* (0.0386)
Age of the firm (squared)	-0.000189 (0.000136)	0.000173 (0.000253)	0.000196 (0.000589)	-0.00145** (0.000659)
Log monthly profits	0.144*** (0.039)	0.0871 (0.061)	0.146** (0.060)	0.0156 (0.181)
Number of full time paid workers (Ref. None)				
1 or 2 full time workers	0.172 (0.148)	0.246 (0.191)	0.247 (0.226)	0.260 (0.348)
3 or more full time workers	0.455* (0.261)	0.0227 (0.386)	0.725* (0.422)	0.903 (0.794)
Level of informality (Ref. Low level)				
High level of informality	0.331 (0.214)	0.839** (0.328)	-0.534 (0.391)	1.207*** (0.415)
Totally informal	0.401** (0.199)	0.085 (0.317)	-1.193*** (0.369)	0.589 (0.410)
Access to electricity	0.409*** (0.124)	0.463** (0.183)	0.454** (0.178)	0.394 (0.377)
Separate finance	-0.185 (0.124)	0.0481 (0.193)	-0.144 (0.174)	-0.162 (0.321)
Bank account	0.710*** (0.166)	0.440** (0.222)	0.722*** (0.224)	0.747** (0.334)
No bookkeeping	-0.518*** (0.152)	-0.489** (0.217)	-0.297 (0.186)	-0.658** (0.317)
Sector of activity (Ref. Manufacture)				
Service	-0.304 (0.194)	-0.0245 (0.323)	-0.533* (0.291)	-1.006 (0.697)
Selling/Trading	-0.751*** (0.161)	-0.375 (0.249)	-0.963*** (0.283)	-1.889*** (0.588)
Urban location	0.122 (0.133)	-0.046 (0.174)	-0.012 (0.212)	0.157 (0.303)
B2B relations	0.734*** (0.172)	0.890*** (0.247)	0.474* (0.276)	0.744* (0.418)
Formal partners	0.471*** (0.119)	0.364** (0.156)	0.488*** (0.183)	0.527* (0.292)
Not local trading partners	0.836*** (0.251)	1.763*** (0.455)	0.495 (0.370)	1.051** (0.502)

(continued on next page)

	(1)	(2)	(3)	(4)
	All	Survivalists	Constrained gazelles	Top performers
Number of ICT devices owned (Ref. Zero)				
1	1.159*** (0.142)	0.902*** (0.173)	1.515*** (0.220)	0.662 (0.463)
2	2.129*** (0.348)	1.896*** (0.730)	2.291*** (0.500)	1.770** (0.741)
3	3.299*** (1.117)	-	3.070*** (0.901)	-
Constant	0.776** (0.389)	0.0581 (0.567)	-0.169 (0.642)	2.596* (1.431)
Region effects	Yes	No	No	No
Country effects	No	Yes	Yes	Yes
Pseudo R2	0.376	0.303	0.347	0.324
Observations	3191	1287	1297	601

Notes: *p < 0.05, **p < 0.01, ***p < 0.001. Robust standard errors in parentheses.

Source: Author's computations based on After Access Surveys, RIA, 2017-2018.

Chapter 2

Digital Technologies, Trading Network, and Informal Firm Performance: Evidence from sub-Saharan Africa

Abstract.

Using data from six sub-Saharan African countries, this chapter investigates how using digital technologies for market coordination with suppliers or customers affects informal firms' economic performance. We rely on two-stage least squares (2SLS) estimation to address endogeneity issues. We instrument this specific usage by the level of digital technologies diffusion among surrounding households and firms, while controlling for a broad set of firm, entrepreneur, and economic environment characteristics. Our findings show that digital bilateral market coordination significantly increases informal firms' monthly sales, value-added, and profit. We find no evidence of heterogeneous effects, regardless of firm and entrepreneur characteristics, highlighting the absence of a third-level digital divide for this usage. Further, we estimate simultaneous equation models using three-stage least squares (3SLS) to understand the channels through which this basic usage of digital technologies enhances informal firms' performance. We find that digital bilateral market coordination affects the trading network of informal firms, contributing to the accumulation of social capital and the expansion of their market reach.

1. Introduction

Despite persistent digital inequalities, mobile telephony is becoming ubiquitous in sub-Saharan Africa, with 500 million unique mobile subscribers (GSMA, 2021) and 89% of the population with mobile network coverage in 2021 (ITU, 2021). Mobile phones offer opportunities for access to a broad set of digital technologies, including the internet and innovative applications and services such as mobile money. However, above all, the diffusion of these technologies constitutes a significant technological transformation in how people communicate with each other and, therefore, how they share and access information, which may have a variety of tangible economic benefits (Goldfarb and Tucker, 2019).

These economic benefits primarily stem from better individuals' economic decisions derived from a significant reduction in information search costs, as mobile phones and their diverse functions make it easier and cheaper to gather information (Leff, 1984). Indeed, digital technologies reduce communication costs by allowing people to communicate at a distance, avoiding the costly and time-consuming personal travel required for face-to-face discussions (Ling and Haddon, 2017). In addition, these alternative search technologies empower individuals in their information search process as the available information is accessible instantly and on demand. They can also search information on a more regular basis, which provides them with the most up-to-date information, and improves its reliability, as they can verify it using multiple sources. Given the low penetration of the internet in sub-Saharan Africa, these mechanisms rely mainly on already existing network since the mere possession of a mobile phone does not, in theory, reduce the cost of searching for new contacts (Aker et al., 2020; Rudder, 2020).

In developing countries, these economic benefits have been widely documented in agricultural economics, highlighting the positive impact of mobile phone coverage extension on agricultural markets efficiency (Jensen, 2007; Aker and Mbiti, 2010; Tack and Aker, 2014; Aker and Fafchamps, 2015; Parker et al., 2016; Muto and Yamano,

2009; Shimamoto et al., 2015; Fernando, 2021). This improved access to information and communication can also benefit non-agricultural informal activities, from which a significant fraction of people earn their livings in sub-Saharan Africa (Bonnet et al., 2019). Compared to their formal counterparts, informal firms are smaller, less productive, and face higher external constraints such as limited access to credit and public utilities (La Porta and Shleifer, 2014; Grimm et al., 2012). Given the persistence of informality (Sen et al., 2022), increasing the productivity of informal workers and firms is emerging as a priority for policymakers, in which the dissemination of digital technologies may have great potential (Choi et al., 2020; Ngumkeu and Okou, 2021). Indeed, as for all other types of businesses, access to information is crucial for microenterprises, their economic activities relying heavily on information flows all along their supply chain (Casson, 2001; Jensen and Miller, 2018).

Digital technologies can potentially improve market coordination with the firm's partners by lowering communication and information costs (Norton, 1992). In sub-Saharan Africa, informal entrepreneurs rely on digital technologies principally for bilateral or one-to-one interactions with suppliers or customers (Esselaar et al., 2006; Berrou et al., 2020). Hence, firms that use digital technologies to communicate with their suppliers may benefit from lower search problems, as they can access information in real-time on inputs' availability, prices, and quality (Bernard et al., 2019). Along with this reduction in search costs, the negotiation and management at the distance of input orders, payment, and delivery, are expected to reduce the overall transaction costs faced by small-scale firms (Jagun et al., 2008). Thus, bilateral coordination with suppliers can enable firms to manage their supply chain more effectively to avoid stock-out or lack of storage space, which seems particularly crucial for small firms facing high activity fluctuations and demand uncertainty, as well as limited storage space (Aker and Mbiti, 2010). Similarly, digital technologies can improve communication and information flows with customers prior to, during, and after trading transactions. Indeed, digital technologies enable firms to provide price and goods characteristics information at a distance and better access to demand characteristics in return (Sife et al., 2010). Bilateral coordination with customers

can improve order follow-up during transactions by communicating information related to the production process, the payment, or the delivery modalities (Esselaar et al., 2006). After the transaction, the use of digital technologies can encourage customer feedback and generate new transactions through individual-specific marketing practices (Molony, 2006). Through this better coordination with customers, being a user of digital technologies can create a comparative advantage over non-user competitors (Jagun et al., 2008). The reduction in search costs extends to all kinds of relationships firms have. Bilateral coordination with competitors can enable firms to harmonize their output prices or share business opportunities, and interactions with national and local authorities can also facilitate access to information about administrative procedures, such as registration or payment of taxes (Nguimkeu and Okou, 2019). Finally, by improving firms' access to knowledge, digital technologies provide opportunities to adopt best practices and new production techniques, acquire new skills, find inspiration and advice, as well as increase their awareness of the regulatory framework (Fafchamps and Quinn, 2018; Paunov and Rollo, 2016; Aker and Blumenstock, 2015; Aker et al., 2012).

However, the introduction of distance into trading activities may generate new moral hazards and contracting problems (Startz, 2016), such as information asymmetries regarding the quality of goods and the effective completion of payment or delivery (Jagun et al., 2008). Therefore, in the presence of weak contract enforcement (Fafchamps, 2004), remote interactions through digital technologies tend to be a complementary communication channel to face-to-face meetings. This is particularly the case among small informal enterprises in sub-Saharan Africa, whose business network remains locally embedded and whose business transactions traditionally involve trading in cash with known agents (Berrou and Gondard-Delcroix, 2018; Berrou and Combarnous, 2012; Duncombe and Heeks, 2002; Jagun et al., 2008). Nevertheless, by reshaping social interactions, digital technologies can help strengthen existing business relationships through frequent contact with suppliers and customers (Eggleson et al., 2002; Donner, 2006), and enhance firms' social capital (Islam et al., 2018b). Repeated interactions can increase mutual trust, monitoring, and enforcement into trading activities (Aker

and Blumenstock, 2015; Fafchamps, 2006), leading to higher reliability of the firm's partners, generating new relational contracting with suppliers (Rudder, 2020), and building customer loyalty (Molony, 2009). While bilateral coordination through digital technologies can strengthen the existing trading network, it can also reshape it by extending the firm's market reach (Donner, 2006). By enabling remote communication, digital technologies make it possible to maintain commercial relations with partners farther away than in the direct vicinity of the business (Atiyas and Dutz, 2021).

Studies examining the role of digital technology usage in business performance in developing countries are sparse and often limited to small, medium, or large formal firms for which data are more available and numerous (Commander et al., 2011; Motohashi, 2008; Cariolle et al., 2019; Paunov and Rollo, 2016; Cirera et al., 2016, 2021; Islam et al., 2018a; Hjort and Poulsen, 2019). However, the limited empirical evidence on informal firms shows they also benefit from adopting these new technologies. Esselaar et al. (2006) is one of the first studies to examine digital technologies' effect on informal firms' performance in sub-Saharan Africa. Using a large but non-random sample of urban firms in 13 African countries, they reported that the use of digital technologies, mainly for bilateral coordination purposes, is associated with higher labor productivity and profitability, regardless of the firms' level of informality. Atiyas and Dutz (2021) demonstrate that access and use of digital technologies are significantly correlated with better microenterprises' performance in Senegal. They further find that labor productivity and total sales, as well as the probability of exporting, are statistically and positively correlated with many specific uses of digital technologies, whether they are used for external business transactions or internal management. Eekhout et al. (2022) explore the association between different mobile phone user profiles and the economic performance of informal businesses from Dakar in Senegal. They find that compared to the "disconnected freelancers," who are mainly subsistence entrepreneurs with extremely basic and low-intensity business uses of mobile phones, the "networkers" who mobilize bilateral coordination with business partners extensively and frequently, have significantly better economic outcomes.

These studies reveal a strong correlation between the use of digital technologies, especially for bilateral coordination purposes, and the economic performance of informal firms. To date, Danquah and Owusu (2021) is the only study that provides robust empirical evidence of a causal effect of digital technologies access on the performance of informal firms. Addressing reverse causality by implementing an IV LASSO method, the authors find that access to digital technologies equipment has a large and positive structural effect on the labor productivity of informal non-farm enterprises in Nigeria. However, the use of digital technologies is not directly observed since the respondents' access to a mobile phone, a computer, or the internet is only collected without knowing whether they use them for professional or strictly private purposes.

In this chapter, we estimate the effect of digital technologies usage for bilateral coordination with trading partners on the economic performance of 2,558 informal non-agricultural firms in six sub-Saharan African countries¹. We use the After Access business surveys conducted by Research ICT Africa (2020) in 2017-18 which provide a random but not representative national sample of firms for each country. As the use of digital technologies has the potential to reshape the way informal firms communicate, access and provide information, and conduct transactions along their value chain, our central assumption is that bilateral coordination with trading partners has a significant and positive impact on informal firms' economic performance, measured as total monthly sales. To address endogeneity issues, we apply two-stage least squares (2SLS) estimation and rely on two instrumental variables reflecting the stage of diffusion of these technologies in the firm's geographical environment. Then, we test whether informal firms are vulnerable to the third-level digital divide, which suggests that individuals benefit differently from using digital technologies depending on their characteristics (Scheerder et al., 2017). Specifically, we examine whether digital bilateral coordination has distributional effects on firms' sales, and whether there are differences in effect by gender, urban/rural location, level of informality, and firm size. Further, we analyze the potential pathways through which digital technologies can affect informal firms'

¹Senegal, Ghana, Nigeria, Kenya, Tanzania, and Mozambique.

economic performance using simultaneous equation models (3SLS). We test whether the use of bilateral coordination strengthens existing business relationships, thereby reducing transaction costs and increasing the social capital of informal firms. We also aim to investigate whether this usage extends the market reach of firms by reshaping their business network.

We find that digital technologies usage for bilateral coordination with trading partners increases informal firms' economic performance. After controlling for endogeneity and all confounding factors, digital bilateral coordination increases the firm's sales by about 140%. The low level of performance of the sampled firms can explain the high magnitude of this effect. Our results are robust to various robustness checks, such as introducing district fixed effects and varying instrumental variables. Moreover, similar effects are observed when considering net profit and value-added as outcome variables and using a more restrictive definition of informality. We find no heterogeneous effects according to the gender of the entrepreneur, the firm's urban or rural location, level of informality, or size. Informal firms in our sample seem to benefit from using digital technologies for bilateral coordination with trading partners regardless of their characteristics. Only the most successful informal firms, in the top quintile of the distribution of sales, appear to not significantly benefit from these basic uses of digital technologies. Concerning the potential pathways of this effect, the econometric results show that digital bilateral coordination is likely to strengthen existing business relationships by increasing the frequency of communication with suppliers, their reliability, and the probability of engaging in relational contracting with them. We then conclude that digital bilateral coordination leads to better economic performance partly through the pathways of social capital accumulation and reduction in transaction costs. Similarly, results show that the extension of market reach is also involved in the mediation process, as bilateral coordination increases the number of upstream relationships maintained by informal firms, and the probability of having distant or formal trading partners.

The remainder of this chapter is organized as follows. Section 2 details our empirical methodology and identification strategy. Section 3 presents the data by briefly describing

the informal firms studied and the variables used in the empirical strategy. Section 4 presents the results of the main regressions, the findings related to the third-level digital divide, and the potential pathways of the effect. In Section 5, we perform several robustness tests on the main estimation results. Finally, we discuss the results and conclude in Section 6.

2. Empirical methodology

2.1 Strategy for estimating the effect of digital bilateral coordination on informal firms' performance

To assess whether there is a link between the use of digital technologies for bilateral coordination with trading partners and the economic performance of informal firms, we use the following standard production function:

$$Y_{i,j,k} = \beta_0 + \beta_1 K_{i,j,k} + \beta_2 L_{i,j,k} + \beta_3 DT_{i,j,k} + \sum_n \gamma X_{i,j,k} + \epsilon_{i,j,k}, \quad (1)$$

where Y_{ijk} is the economic outcome variable for firm i in sector j in country k . K_{ijk} stands for the log of physical capital. To ensure that we obtain unbiased estimates of the returns to capital, we follow Battese (1997) by setting K_{ijk} to zero for firms with no capital and add a dummy variable that takes the value 1 for those firms, 0 otherwise. L_{ijk} is the log of the number of full-time paid workers and owners working for the firm. DT_{ijk} is a dummy variable equal to 1 if firm i uses digital technologies to communicate with trading partners (suppliers or customers). X_{ijk} is a vector of n control variables, including entrepreneurs, firms, trading partners, and economic environment characteristics. All models control for sector and country fixed effects. To account for heteroskedasticity and serial correlation, ϵ_{ijk} is an error term clustered at the enumerator area (EA) level.

The coefficient of interest β_3 estimates the extent to which bilateral coordination with suppliers or customers through digital technologies affects the economic performance

of informal firms. The main assumption is that this coefficient of interest is larger than zero. We estimate the production function for the firm's monthly sales. This outcome variable is log-transformed due to large kurtosis and skewness values. We associate the value of monthly sales with the extensive margin as it captures the firm's ability to sell its output of goods or services, and to multiply economic transactions. We do not have precise data on labor productivity that would allow us to measure the effect of digital bilateral coordination on the intensive margin, but we test alternative dependent variables in robustness checks.

Estimating equation (1) with ordinary least squares (OLS) estimators may lead to biased coefficients $\hat{\beta}_3$ due to several endogeneity issues. First, unobserved heterogeneity between users and non-users of digital technologies for bilateral coordination may cause the variable of interest to be correlated with the error term, leading to a biased estimated coefficient. Indeed, the determinants of digital technologies usage are diverse, ranging from access to infrastructure, individual characteristics and perceptions, and structural characteristics of firms. Hence, an omitted variable bias is likely to occur because firms self-select into the user group.

Second, endogeneity may arise from simultaneity in the determination of informal firms' economic performance and their decision to use digital technologies for business purposes. As our main assumption states, the use of digital technologies for bilateral coordination is expected to increase the economic performance of informal firms. At the same time, higher economic performance may lead to a greater ability to pay for digital devices and services, and a higher need to integrate these new technologies into the firm's production process. The disparities in the usage of digital technologies between subsistence entrepreneurs and the most successful informal firms, as highlighted in the first chapter, effectively illustrate the potential presence of a simultaneity bias. Indeed, while only one-third of survivalists rely on digital technologies for bilateral coordination, almost all top performers do so (85%).

To address the endogeneity bias resulting from applying OLS to equation (1), we rely on two-stage least squares (2SLS) regression analysis. We instrument the use of

digital technologies for bilateral coordination using two variables: (i) the proportion of households owning digital technologies² at the EA level, and (ii) the proportion of firm's peers³ in a radius of 50 kilometers (km) using digital technologies for bilateral coordination. As the endogenous variable includes bilateral coordination with customers and suppliers, the two instruments are each particularly relevant for one of the channels of bilateral coordination. These variables are valid instruments if they satisfy two requirements. On the one hand, the instruments must be relevant, i.e., significantly correlated with the endogenous variable, even after controlling for confounding factors. On the other hand, instruments must be excludable, i.e., conditionally independent from the error term in equation (1). Hence, the instrument must affect the outcome variable only through its effect on the endogenous variable and not through other omitted variables.

Both instruments are relevant as they are likely to affect the probability that firms use digital technologies for bilateral coordination with their partners. Indeed, the ownership of digital technologies among households in the direct vicinity of the firm reflects the stage of diffusion of these technologies in the firm's geographical environment. The level of diffusion is likely to affect the likelihood that firms own or can access digital technologies, which is a precondition for any specific usage. Furthermore, a higher prevalence of digital technologies ownership at the geographic level among households may enhance the firm's opportunity to use digital technologies for communicating with surrounding potential customers. Kikulwe et al. (2014) and Miyajima (2020) use similar instruments for the adoption of mobile phones or mobile money by households in Kenya and South Africa.

The second instrument, the proportion of the firm's peers⁴ within a 50 km radius using digital technologies for bilateral coordination, is also likely to influence the use of digital technologies by the firm. As described in the first chapter, adoption and usage patterns

²Including mobile phone, landline phone, computers, and an internet connection.

³Firm's peers are other firms surveyed in a same country.

⁴By focusing on the behavior of firm's peers, we avoid the arithmetic correlation between the use of digital technologies by individual i and the average level of digital technologies usage in the population to which he belongs (Angrist and Pischke, 2009).

differ according to the traits of entrepreneurs and firms, and their infrastructural access to digital technologies. However, adopting a technology requires knowledge and awareness of its usefulness, which often comes from interaction with other agents (Comin and Mestieri, 2014). These interactions are shaped by geography, particularly by firms' competitive and business environments. Therefore, the level of peers' adoption can influence the firm's decision to adopt digital technologies and their specific usage through peer effects. It also gives a good estimate of the level of adoption among the firm's surrounding potential suppliers. As informal firms tend to source their inputs in a larger geographic area than they sell their outputs, we consider all the firm's peers in a radius of 50 km⁵. In addition, considering peers within a broad geographical radius rather than at the EA level limits the risk that the instrumental variable (IV) is endogenous due to the potential spatial clustering of successful firms⁶. Bertschek and Niebel (2016) have proposed a similar approach, as they have instrumented mobile internet access at the firm-level by the average share of mobile internet use at the industry level in Germany.

Therefore, as the first stage of the 2SLS regression, we estimate the following equation:

$$DT_{i,j,k} = \alpha_0 + \alpha_1 HH_{i,j,k} + \alpha_2 Peers_{i,j,k} + \sum_n \phi X_{i,j,k} + \epsilon_{2,i,j,k}, \quad (2)$$

where HH_{ijk} is the average rate of digital technologies ownership among households in the EA of the firm i , and $Peers_{ijk}$ is the proportion of firm i 's peers in a 50 km radius that are using digital technologies for bilateral coordination with trading partners. X_{ijk} is a vector of control variables, including input factors, entrepreneurs, firms, trading partners, and economic environment characteristics, as well as sector and country fixed effects.

Concerning the validity of the instruments, the exclusion restriction raises more concerns as it is often difficult to find completely exogenous instruments. Indeed, it implies that both instruments affect the economic performance of the firms only through their influence on the firms' use of digital technologies for bilateral coordination purposes.

⁵We chose a radius of 50 km instead of calculating the average in the district of the firm, as administrative subdivisions may vary in size and population density across the countries considered.

⁶If the firm self-selects into an EA with high economic activity and successful firms, the exclusion restriction would risk being rejected for the second instrument.

We identify three potential sources of bias due to correlation with confounding factors or indirect impact channels on informal firms' performance, which we address by introducing control variables.

First, the stage of diffusion of digital technologies in the area may be only partially exogenous, as unobserved factors that directly influence it may also affect the economic performance of the firms (Buys et al., 2009). This is the case for the overall level of economic activity, household income, or the disparities in the deployment of telecommunications infrastructure in the region. In the same way, peers' use of digital technologies may not only affect the probability that the firm adopts such practices, but also have some local externalities or spillovers, such as inducing lower average transaction costs or market frictions, that affect the economic performance of firms, whether or not they are users. Following Naito et al. (2021), we address these potential sources of bias by including two control variables for disparities in economic activity at the geographical level: the average night light luminosity in 2013 derived from satellite imagery data (NOAA, 2013) and the population density in 2015 within a 5 km radius of each firm's location (CIESIN, 2018)⁷⁸. In addition, we add a dummy that indicates whether the firm is in the range of a cell tower providing 3G or 4G network⁹ as a control variable for telecommunication infrastructural access.

Second, both instruments may affect firms' performance through channels other than bilateral coordination with trading partners, as they are also correlated with digital technologies ownership and other specific uses at the firm-level. The estimated coefficient of interest would be biased upward, as it would capture the effect of bilateral coordination on the firm's performance but also the effect of these other digital technologies-related behaviors (Aker and Blumenstock, 2015). One concern is the potential increase in sales through other non-bilateral transactions, such as online transactions. However, only a

⁷These control variables are considered for years prior to the implementation of the survey to minimize endogeneity.

⁸Naito et al. (2021) also include the average built-up rate in the area to control for urbanicity. In our case, adding this additional variable would bring redundant information due to the high correlation with average night light luminosity (Pearson's correlation coefficient equals 0.82). The Variance Inflation Factor (VIF) for this variable approaches the threshold value of 5.

⁹We restrain the access to more advanced technologies because GSM coverage is common in the sample (91%) and roll-out of 3G and 4G technologies may traduce a higher quality of digital connectivity.

few businesses have received at least one online order in the last month (2.9%). To address these issues, we include dummies as control variables for digital technologies ownership, use of the internet and social media, and mobile money usage.

Finally, we recognize that the stage of diffusion of digital technologies in the firms' environment may also affect the type of business relationships they can establish and maintain. On the one hand, the proliferation of digital technologies has the potential to strengthen already existing business relationships by enabling more frequent contacts, for example. On the other, digital technologies have the potential to shape the informal firm's business network by allowing them to extend their geographical market reach by sourcing inputs or selling their production further away than the surrounding neighborhood. Hence, characteristics of trading network are important confounding factors in our estimation strategy. As they are correlated to the stage of diffusion of digital technologies in the firms' environment, the probability that they use digital bilateral coordination, and their economic performance, not controlling for business network characteristics could generate an omitted variable bias and prevent instruments from verifying the necessary condition of exclusion restriction. Thus, to control for these confounding factors, we include a set of dummy variables that describe the characteristics of trading partners and relationships¹⁰.

2.2 Heterogeneous effects of digital bilateral market coordination on informal firms' sales

Given the strong heterogeneity of informal firms, the adoption of such usage may have heterogeneous effects depending on the characteristics of the entrepreneur and the firm, with important policy implications in terms of targeting. Hence, after estimating the average effect of digital bilateral market coordination on informal firms' performance,

¹⁰We control for whether the firm has formal suppliers, suppliers or customers located further away than the surrounding towns and villages, relationships with its most important suppliers or customers for more than three years, businesses as customers, very reliable most important suppliers, communicate weekly with most important suppliers, and is engaged in relational contracting with trading partners. We consider that a firm is engaged in relation contracting if they have a line of credit or credit facility with suppliers, or they offer a credit line facility to some customers.

we first explore whether this usage has non-linear and distributional effects on firms' monthly sales. We use the instrumental variable quantile regression model proposed by Chernozhukov and Hansen (2005)¹¹, which allows us to estimate the effect of digital bilateral market coordination on firms' sales at different points in the conditional distribution of monthly sales ($q = 0.2, 0.4, 0.6, 0.8$), while addressing endogeneity issues.

Then, we test the existence of a third-level digital divide according to the entrepreneur's gender, the firm's urban location, level of informality, and size. We test these sources of heterogeneity in the effect of bilateral coordination on the economic performance of informal firms by including interaction terms in equation (1), combining the endogenous variable (digital bilateral market coordination) and the potential source of heterogeneity. For the instrumental variable of the interaction term, we use the interactions between the instruments and the variable of interest.

2.3 Pathways of the effect of digital bilateral market coordination on sales

Finally, we explore the potential pathways through which digital bilateral market coordination may affect the informal firm's economic performance. We test two hypotheses. First, that the use of digital technologies for bilateral coordination strengthens the business networks of informal firms, allowing for the accumulation of social capital and the reduction of transaction costs, which in turn increase the firm's economic performance (Islam et al., 2018b). This first pathway is explored by investigating whether four different variables are involved in the mediation process of the causal relationship studied. We successively consider whether the firm communicates weekly with its most important suppliers, is engaged in relational contracting with suppliers or customers, has relationships with its most important suppliers or customers for more than three years, and whether the entrepreneur perceives the most important suppliers as very reliable. The second hypothesis states that digital bilateral market coordination has

¹¹We use the *sivqr* stata command (Kaplan, 2022), which implements the smoothed estimator of Kaplan and Sun (2017).

the potential to reshape the firm's business network by expanding its market reach and increasing the number and type of relationships maintained (Donner, 2006). We explore this second pathway by investigating the association of four variables with digital bilateral market coordination and economic performance. We successively consider whether the firm has more than three different suppliers, has trading partners with formal status, has businesses as customers, and has trading partners that are located further away than the surrounding towns and villages.

We estimate these simultaneous equation models using three-stage least squares (3SLS) (Zellner and Theil, 1992). Following a similar methodology to Clement et al. (2021), the equations system for a given pathway can be formulated as follows:

$$\begin{cases} DT_{i,j,k} = \alpha_0 + \alpha_1 HH_{i,j,k} + \alpha_2 Peers_{i,j,k} + \sum \phi X_{i,j,k} + \epsilon_{2,i,j,k} \\ Path_{i,j,k} = \gamma_0 + \gamma_1 DT_{i,j,k} + \sum \psi X_{i,j,k} + \epsilon_{3,i,j,k} \\ Y_{i,j,k} = \beta_0 + \beta_1 K_{i,j,k} + \beta_2 L_{i,j,k} + \beta_3 Path_{i,j,k} + \sum \gamma X_{i,j,k} + \epsilon_{i,j,k} \end{cases} \quad (3)$$

The first equation is similar to the first stage of the 2SLS estimation model described above (equation (2)). The second equation estimates the effect of digital bilateral market coordination on the variable considered as a potential pathway, noted $Path_{ijk}$. The third equation estimates the impact of the considered pathway on the informal firm's economic performance. In each equation, the vector of control X_{ijk} includes the entrepreneur's, firm's, and EA's characteristics, sector and country fixed effects, as well as other potential pathways. In the first and second equations, it also includes the input factors K_{ijk} for the log of physical capital and L_{ijk} for the log of the number of full-time paid workers and owners working for the firm.

3. Data

3.1 The sample

We use the After Access business surveys conducted by Research ICT Africa (2020) in 2017-18 across nine African countries¹², to implement our estimation strategy. We remove observations from three countries for several reasons. Firstly, we do not include data from Uganda due to large missing values on economic performance variables. Second, we remove the observations from South Africa, as the EA identifiers are not available. This prevents us from matching business and household surveys across enumeration areas and using the household survey to find valid instrumental variables. Due to its upper-middle income status and advanced level of digitalization, the removal of South Africa's observations increases the homogeneity of our sample but makes it less representative of the macroeconomic situations of sub-Saharan African countries. Finally, we remove the data from Rwanda because we found discrepancies between the GPS positions of the firms and the EA assigned to them. In fact, some enterprises that belong to the same EA according to the database are several tens of kilometers apart. Such inconsistencies would have led to biased instruments, as they are based on the geographical proximity between the firm and its peers or surrounding households.

Surveyed firms are not necessarily informal, as no filter questions associated with a definition of informality have been implemented in the sampling frame. To identify informal firms, we construct an informality index that takes into account five criteria¹³. We restrict our analysis to the sample of informal firms and non-agricultural activities, as formal firms are few in the sample¹⁴, and agricultural activities have specific productive characteristics. Our final sample thus comprises 2,558 informal firms from six sub-

¹²Senegal, Ghana, Nigeria, Rwanda, Uganda, Kenya, Tanzania, Mozambique, and South Africa.

¹³Namely: (1) being registered with a local authority or municipality, (2) being registered at the general registrar, (3) paying local or municipal taxes (tax stamps), (4) being registered for national VAT or sales tax, and (5) keeping accounts according to national or regional standards.

¹⁴Only 1.6% of firms satisfy all five criteria considered in the informality index.

Saharan African countries: Senegal, Ghana, Nigeria, Kenya, Tanzania, and Mozambique (Table 1).

3.2 The endogenous variable

Our estimation strategy aims to assess whether the use of digital technologies to communicate in a bilateral, or one-to-one, way with trading partners affects the firm's economic performance. Our endogenous variable is derived from two specific survey modules that examine supply chain and customer characteristics. Whether firms use digital technologies for bilateral coordination with suppliers is derived from the following question: "How does the firm usually communicate with its suppliers?" Similarly, bilateral coordination with customers is captured by the question: "How does the firm usually communicate with its customers?" For the two questions, we consider that firms use digital technologies for bilateral coordination with suppliers or customers if they indicate at least one interface among mobile phone, landline phone, email, SMS, and fax. To ensure that we exclusively focus on bilateral coordination, we do not include social media as such interfaces facilitate multilateral coordination¹⁵.

In the sample, 43% of firms are engaged in bilateral coordination with their suppliers through digital technologies, while approximately the same percentage of firms (44%) are involved in bilateral coordination with customers. These are the most common reasons for using digital technologies in our sample of informal firms. These two specific uses of digital technologies are significantly correlated. About three-quarters of the firms that practice bilateral coordination with their suppliers also do it with their customers, and conversely. This high correlation would prevent distinguishing the specific effect of each on the economic performance of firms. So, although each type of coordination may not have the same effect on firm performance, we combine them to create the endogenous variable considered in equation (1). This variable indicates whether firms use digital technologies for bilateral coordination with their trading partners, whether they are

¹⁵No significant differences emerge when we consider social media as a means of bilateral coordination with trading partners, as only six firms use it without using another interface.

suppliers or customers. Almost all of the firms involved in these uses (96%) perform them using their mobile phone only¹⁶. It clearly illustrates the hegemony of mobile phones as the main device used by informal firms to access digital technologies. This does not allow us to analyze whether the number of interfaces through which firms perform these bilateral coordination uses affects the relationship under study.

3.3 Instrumental variables

We instrument our endogenous variable by two instrumental variables. The first instrument that measures the proportion of households owning digital technologies in the enumeration area of each firm is derived from the After Access Household surveys, conducted by Research ICT Africa (2020) in parallel with the business surveys used in the analysis¹⁷. Due to the inability to match EA identifiers between the enterprise and household survey frames, the proportion of households with digital technologies is calculated at the district and urban/rural levels for Senegal, and at the regional and urban/rural levels for Kenya, resulting in a lower variance in the household equipment rate for these two countries. The second instrument, which measures the proportion of other surveyed firms in a 50 km radius¹⁸ that use digital technologies for bilateral coordination, is derived from the GPS information of each firm's location.

3.4 Dependent variables

In equation (1), we consider the logarithm of monthly sales as a dependent variable to assess the effect of digital bilateral market coordination on the economic performance of informal firms. In robustness checks, we estimate this equation for two other dependent variables: the value-added and the net profit. The value-added is measured as sales minus

¹⁶We add up the modalities "mobile phone" and "SMS."

¹⁷In calculating the average at the EA level, we take into account the household sampling weights available in the After Access household survey database. No significant difference is observed in the results, whether or not we use the sampling weights for calculating the first instrument.

¹⁸Although we do not restrict this radius to national borders, none of the firms has a foreign firm within its 50 km radius.

fixed and intermediate costs. The net profit of the enterprise is asked directly from the entrepreneurs and therefore, unlike value-added, is not directly linked to the estimation of sales. As financial outcomes reported by entrepreneurs are expressed in local currency, we use the 2017 Purchasing Power Parity (PPP) conversion factors to adjust for price differences between countries and convert them into international \$¹⁹.

To mitigate the influence of extreme values on the average for each country, Table 1 reports the trimmed average monthly values for these dependent variables. The overall average monthly sales is 783\$, with average monthly value-added and profit standing at \$442 and \$203, respectively. We observe significant differences between countries in terms of level of financial performance. Informal firms in Mozambique have the lowest level of performance, while Senegalese firms appear to perform better than others on average.

3.5 Control variables

Table 1 reports descriptive statistics on the characteristics of firms and entrepreneurs. The proportion of firms led by women is slightly lower than that of men, while 6% of businesses are joint ventures between men and women. 37% of the entrepreneurs have no education, and only 22% and 15% have attained secondary or tertiary education, respectively²⁰. Considering input factors of production, firms in the sample are mainly micro-sized with less than five full-time paid workers. Moreover, the absence of full-time paid workers is widespread, with 67% of entrepreneurs being self-employed without permanent employees. The average amount of fixed capital is \$534, and 34% of the entrepreneurs declare that they do not own any fixed assets of value (machinery, vehicles, or furniture). It is consistent with the low prevalence of electricity access in business premises (54%). The vast majority of businesses are not considered by any registration or taxation. At the same time, half of them keep accounts that do not comply with standards. This low level of formality is combined with low financial inclusion, as only

¹⁹In the database, the value of sales and profits is expressed in annual values for Tanzania. We have therefore harmonized the measures by dividing these values by 12.

²⁰If there are several owners, we consider the one with the highest level of education. Similarly, for the age of the owner, we consider the youngest owner.

19% of businesses have access to a bank account. However, half of the sampled firms have trading partners with a formal status, mainly small or large formal enterprises as suppliers. Regarding the structure of their trading network, 23% of enterprises report that they have no external suppliers to the household, most of them producing what they sell²¹. We note that 22% have other businesses as customers, and only 10% have business partners located further away than the surrounding towns and villages. 42% have been doing business for more than three years with their most important customers or suppliers, and only 19% perceive the latter as very reliable. Almost half of the surveyed firms are engaged in relational contracting with trading partners and communicate weekly with their most important suppliers. Finally, most firms (78%) have access to digital technologies, with mobile phones being the principal device owned, as ownership of computers and landline phones is extremely rare. Other uses of digital technologies for business purposes are much less widespread than bilateral coordination. Only 11% of firms use the internet or social networks for multilateral coordination, while 27% use mobile money services to send or receive money.

In order to control for economic activity and infrastructural access at the firm-level, we rely on other data sources. We use cell towers' location derived from OpenCelliD (2023) to determine whether the firm is covered by a 3G or 4G network. This database provides the GPS coordinates of cell towers in an approximate range, their signal type, and the date they were added to the database. We consider all cell towers located in the six countries considered in the analysis and for which the year of creation is prior to the year of the business survey. An issue with the data provided by OpenCelliD is that the location of cell towers is derived from mobile phone users. As a result, cell towers location tend to be concentrated along roads and in urban centers. To account for the potential discrepancy between the estimated and actual location of cell towers, we restrict the sample to cell towers for which the approximate area in which they are located is less than, or equal, to one square kilometer. We assume that each cell tower with a 3G or 4G signal is the center point of a 4 km coverage radius, following the methodology of Collins Bartholomew's

²¹Principally some agricultural products.

Table 1: Characteristics of firms and entrepreneurs

	Kenya	Mozambique	Ghana	Nigeria	Tanzania	Senegal	All
Entrepreneur characteristics							
Man	0.40	0.39	0.42	0.38	0.56	0.68	0.48
Woman	0.49	0.56	0.51	0.57	0.38	0.28	0.46
Joint venture (Woman and man)	0.11	0.05	0.07	0.04	0.05	0.04	0.06
Age	34.9	38.2	39.6	38	37.7	36.8	37.5
No education	0.02	0.47	0.18	0.28	0.69	0.53	0.37
Primary education	0.20	0.35	0.39	0.17	0.24	0.21	0.26
Secondary education	0.49	0.04	0.34	0.40	0.02	0.05	0.22
Tertiary education	0.29	0.13	0.08	0.15	0.05	0.22	0.15
No other opportunity	0.28	0.61	0.53	0.48	0.68	0.44	0.51
Firm economic performance							
Sales	854	252	997	622	632	1843	783
Value-added	514	72	594	307	304	1236	442
Net profit	290	88	287	165	24	542	203
Firm characteristics							
# of full-time paid workers	2.0	1.2	2.2	1.5	1.4	2.3	1.8
Any full-time paid worker	0.59	0.83	0.54	0.79	0.74	0.51	0.67
Physical capital	376	167	1047	564	452	885	534
No capital	0.36	0.48	0.35	0.24	0.13	0.52	0.34
Urban	0.67	0.69	0.63	0.44	0.59	0.67	0.61
Manufacture	0.06	0.18	0.15	0.15	0.10	0.14	0.13
Service	0.25	0.07	0.20	0.18	0.15	0.20	0.18
Trade	0.69	0.76	0.65	0.67	0.75	0.65	0.69
Age of firm	3.6	5.9	6.8	7.6	4.8	6.1	5.9
Registration	0.41	0.11	0.37	0.22	0.17	0.31	0.26
Pay taxes	0.44	0.23	0.49	0.44	0.18	0.42	0.37
Bookkeeping	0.56	0.39	0.35	0.28	0.38	0.95	0.49
Access to electricity	0.63	0.27	0.60	0.56	0.49	0.67	0.54
Bank account	0.28	0.10	0.32	0.26	0.09	0.11	0.19
Trading network characteristics							
Any supplier	0.32	0.15	0.31	0.26	0.17	0.16	0.23
Only one supplier	0.23	0.31	0.24	0.19	0.32	0.31	0.26
Two or three suppliers	0.28	0.38	0.29	0.31	0.36	0.34	0.33
More than three suppliers	0.18	0.16	0.17	0.24	0.15	0.19	0.18
Formal partners	0.52	0.40	0.46	0.48	0.45	0.46	0.46
Businesses as customers	0.35	0.05	0.28	0.28	0.08	0.32	0.22
Not locally located trading partners	0.06	0.04	0.16	0.06	0.05	0.25	0.10
Very reliable suppliers	0.22	0.10	0.26	0.28	0.10	0.19	0.19
Relational contracting	0.53	0.40	0.56	0.69	0.37	0.30	0.48
Long relationship	0.24	0.40	0.49	0.60	0.25	0.50	0.42
Weekly communication with suppliers	0.51	0.54	0.39	0.41	0.46	0.57	0.48
Digital technologies							
Mobile phone	0.87	0.70	0.78	0.66	0.81	0.89	0.78
Computer	0.03	0.02	0.05	0.01	0.03	0.08	0.04
Landline	0.01	0	0.04	0.02	0	0.07	0.02
Mobile money	0.59	0.21	0.37	0.03	0.15	0.33	0.27
Internet and social media	0.10	0.03	0.13	0.09	0.06	0.21	0.11
Bilateral coordination with suppliers	0.63	0.23	0.49	0.41	0.19	0.65	0.43
Bilateral coordination with customers	0.66	0.24	0.56	0.41	0.19	0.60	0.44
Observations	385	393	386	492	453	449	2258

Notes: We report the trimmed mean (trimmed by 5%) for monetary variables which are expressed in 2017 Intl.\$ PPP.

Source: Author's computations based on After Access Surveys, RIA, 2017-2018.

GSMA Mobile Coverage Explorer database. After projecting each cell tower relevant to the criteria and overlaying their coverage radius using QGIS, we use GPS information on each firm's location to determine whether they are covered by a 3G or 4G network.

To control for economic activity in the area of each firm, we include two other variables. We calculate the average population density within a radius of 5 km of each firm's location, using the population density map with a 1 km resolution provided by the Center for International Earth Science Information Network (CIESIN, 2018) for 2015. In addition, we calculate the average night light luminosity within a 5 km radius of each firm's location using satellite imagery data from the National Oceanic and Atmospheric Administration (NOAA, 2013).

4. Results

4.1 The effect of digital bilateral market coordination on informal firms' sales

We seek to assess whether using digital technologies for bilateral coordination with trading partners affects the economic performance of informal firms. Table 2 shows that using digital technologies for bilateral coordination with trading partners increases the informal firm's monthly sales (Panel B). A statistically significant and positive relationship between the dependent variable and the endogenous variable is found both in OLS and IV regressions.

However, the OLS estimate (column 1) is of lower magnitude than the instrumental variables estimates (columns 2-5), as the coefficient increases from 0.360 to at least 1.426. Such an increase in the magnitude of the coefficient is usual in IV estimates, and the economic magnitude of the 2SLS estimates is still reasonable given the low level of informal firms' monthly sales in our sample. Column 3 shows that controlling for levels of economic activity and infrastructural access at the geographic level significantly decreases the estimated coefficient's magnitude (2.337 versus 1.604). It suggests that the stage of diffusion of digital technologies in the area is effectively not completely exogenous, and that not controlling for these disparities across areas would lead to an upward bias in the estimated coefficient and possible rejection of the exclusion restriction.

Table 2: The effect of digital bilateral coordination on firm's sales (OLS and 2SLS results)

	OLS	2SLS			
	(1)	(2)	(3)	(4)	(5)
Panel A: First-stage					
	Dependent variable: Bilateral coordination dummy				
DT equipment rate of EA's households		0.184** (0.072)	0.245*** (0.079)	0.169** (0.071)	0.191*** (0.071)
Bilateral coordination among firm's peers		0.317*** (0.071)	0.321*** (0.070)	0.298*** (0.068)	0.236*** (0.068)
Under-identification test		0.000	0.000	0.000	0.000
Weak instrument test		28.704	29.279	22.176	17.785
Over-identification test		0.347	0.902	0.893	0.951
Endogeneity test		0.000	0.015	0.028	0.059
Panel B: Second-stage and OLS					
	Dependent variable: Log of total monthly sales				
Bilateral coordination dummy	0.360*** (0.070)	2.337*** (0.510)	1.604*** (0.479)	1.584*** (0.562)	1.426** (0.612)
R-squared	0.475	0.217	0.366	0.368	0.404
Control variables					
Controls for firm and entrepreneur	Yes	Yes	Yes	Yes	Yes
Country and sector fixed effects	Yes	Yes	Yes	Yes	Yes
Controls for area-level characteristics	Yes		Yes	Yes	Yes
Controls for ICT equipment and other usage	Yes			Yes	Yes
Controls for trading partners' characteristics	Yes				Yes
Observations	2545	2530	2530	2530	2530

Notes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Standard errors clustered at the EA level.

Column 3 includes as controls the average population density in 2015 and the average night light luminosity in 2013, both within a 5 km radius, and a dummy indicating if the firm is covered by 3G or 4G network. Column 4 adds three dummies to control for digital technology equipment, internet and social media usage, and mobile money usage. In column 5, we add eight additional dummy variables to control for the characteristics of trading partners.

Source: Author's computations based on After Access Surveys, RIA, 2017-2018.

In contrast, introducing additional controls for digital technology ownership and other specific uses (column 4) does not significantly change the estimated coefficient, implying that it only captures the effect of bilateral coordination on the firm's performance, not the effect of these other digital technologies-related behaviors. Finally, controlling for characteristics of trading partners significantly decreases the magnitude of the estimated coefficient, as we can see in column 5. When we control for all confounding factors, our results show that digital bilateral market coordination increases the informal firms' monthly sales by 143% on average.

Panel A presents the first stage of the 2SLS estimation, which confirms the relevance of our estimation strategy. We find that the estimated coefficients of both instrumental variables are highly statistically significant and stable across specifications. In addition, the rejection of the null hypothesis of the under-identification test confirms that the model is identified, i.e., that instruments are correlated with the endogenous variable. As the standard errors are clustered at the EA level, the weak instrument test reports the Kleibergen-Paap Wald rank F-statistic which is higher than 10 for all specifications, indicating that our excluded instruments are not weak. All these elements confirm that the relevancy requirement is verified. Concerning the excludability requirement, the null hypothesis of the over-identification test, stating that the instruments are not correlated with the error term and correctly excluded from the estimated equation, is not rejected, confirming that our instruments are valid and do not violate the exogeneity condition. Finally, the rejection of the null hypothesis of the endogeneity test confirms that there is simultaneity in the determination of informal firms' economic performance and usage of digital technologies, justifying our identification strategy.

4.2 Third-level digital divide: heterogeneous effect of digital bilateral market coordination on firms' sales

In this section, we examine whether the use of digital technologies for bilateral coordination with trading partners has heterogeneous effects among informal firms. We anticipate that a third-level digital divide could emerge, i.e., disparities in benefits derived from access and usage of digital technologies according to the characteristics of individuals (Van Deursen and Helsper, 2015; Scheerder et al., 2017).

First, we estimate the effect of digital bilateral coordination on four different quantiles of monthly sales to observe whether all informal firms benefit homogeneously from these uses, regardless of their level of economic performance. Table 3 summarizes the coefficient estimates from the instrumental variables quantile regression for the 20th, 40th, 60th, and 80th percentiles of the sales distribution. The quantile estimates indicate

Table 3: Distributional effects of digital bilateral coordination on monthly sales (IV quantile regression)

	Dependent variable: Sales quantiles			
	(1)	(2)	(3)	(4)
Panel A: Instrumental variable quantile regression	20%	40%	60%	80%
Bilateral coordination dummy	0.935** (0.453)	0.863** (0.423)	1.277* (0.747)	1.341 (14.469)
Control variables				
Controls for firm and entrepreneur	Yes	Yes	Yes	Yes
Country and sector fixed effects	Yes	Yes	Yes	Yes
Controls for area-level characteristics	Yes	Yes	Yes	Yes
Controls for DT equipment and other usage	Yes	Yes	Yes	Yes
Controls for trading partners characteristics	Yes	Yes	Yes	Yes
Observations	2530	2530	2530	2530

Notes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Source: Author's computations based on After Access Surveys, RIA, 2017-2018.

heterogeneity in the effects of using digital technologies for bilateral coordination with trading partners, which varies across different monthly sales quantiles. Overall, we find positive effects of digital bilateral coordination on informal firms' sales. However, these positive effects are only significant below the 80th percentile of the sales distribution. This can be explained by the fact that the most successful firms already widely use digital technologies for market coordination purposes in their business operations. In contrast, our findings show that the digitalization of business interactions benefits not only the most vulnerable informal firms, but also those with intermediate levels of sales. Thus, while most successful firms probably need access to more advanced uses of digital technologies to increase their productivity and expand their production capacity, basic communication usage of digital technologies holds significant potential for supporting most African informal firms.

Next, we aim to assess whether specific traits of entrepreneurs and firms are a source of disparities in terms of tangible benefits derived from digital technologies usage. We begin by examining whether there is a third-level digital divide based on the entrepreneur's gender. Table 4 presents the second-stage results of the 2SLS estimations introducing the interaction term of the gender and bilateral coordination usage dummies, which provides

Table 4: Heterogeneous effects according to entrepreneur's gender (OLS and 2SLS results)

	OLS	2SLS			
	(1)	(2)	(3)	(4)	(5)
Panel B: Second-stage and OLS					
	Dependent variable: Log of monthly sales				
Bilateral coordination dummy	0.323*** (0.084)	2.431*** (0.560)	1.638*** (0.535)	1.618*** (0.616)	1.415** (0.662)
Bilateral coordination x Woman	0.081 (0.101)	-0.197 (0.267)	-0.088 (0.257)	-0.096 (0.255)	-0.013 (0.248)
Woman	-0.212** (0.085)	0.05 (0.171)	-0.102 (0.169)	-0.100 (0.161)	-0.125 (0.156)
R-squared	0.474	0.217	0.367	0.370	0.406
Control variables					
Controls for firm and entrepreneur	Yes	Yes	Yes	Yes	Yes
Country and sector fixed effects	Yes	Yes	Yes	Yes	Yes
Controls for area-level characteristics	Yes		Yes	Yes	Yes
Controls for DT equipment and other usage	Yes			Yes	Yes
Controls for trading partners characteristics	Yes				Yes
Observations	2545	2530	2530	2530	2530

Notes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Standard errors clustered at the EA level.

Source: Author's computations based on After Access Surveys, RIA, 2017-2018.

information about whether the effect of digital bilateral coordination is the same for firms led by women and men. We find that for male-led firms, digital bilateral coordination increases monthly sales by 141%, and that there is no significant difference between this coefficient and that for female-led firms, as the coefficient of the interaction term is not significant. Thus, we do not find a gender third-level digital divide, as no heterogeneity is observed in the effect of digital bilateral coordination on the firm's monthly sales according to the entrepreneur's gender.

We perform a similar analysis to identify a potential third-level digital divide between urban and rural firms, for which the results are reported in Table 5. Findings show that digital bilateral coordination increases monthly sales by 141% for rural firms. Urban firms benefit from these practices to the same extent, as the coefficient of the interaction term is small and insignificant, although negative. Thus, no urban/rural third-level digital divide is found here, as no heterogeneity is observed in the effect of digital bilateral coordination on the firm's monthly sales, whether firms are located in rural or urban areas.

Table 5: Heterogeneous effects according to firm's location (OLS and 2SLS results)

	OLS	Instrumental variable			
	(1)	(2)	(3)	(4)	(5)
Panel B: Second-stage and OLS					
	Dependent variable: Log of monthly sales				
Bilateral coordination dummy	0.470*** (0.103)	2.131*** (0.499)	1.612*** (0.521)	1.549*** (0.574)	1.412** (0.597)
Bilateral coordination x Urban	-0.183 (0.117)	-0.192 (0.314)	-0.037 (0.302)	-0.035 (0.304)	-0.107 (0.287)
Urban	0.049 (0.104)	0.218 (0.180)	-0.062 (0.185)	-0.061 (0.185)	-0.021 (0.176)
R-squared	0.476	0.289	0.368	0.377	0.415
Control variables					
Controls for firm and entrepreneur	Yes	Yes	Yes	Yes	Yes
Country and sector fixed effects	Yes	Yes	Yes	Yes	Yes
Controls for area-level characteristics	Yes		Yes	Yes	Yes
Controls for DT equipment and other usage	Yes			Yes	Yes
Controls for trading partners characteristics	Yes				Yes
Observations	2545	2530	2530	2530	2530

Notes: *p < 0.05, **p < 0.01, ***p < 0.001. Standard errors clustered at the EA level.

Source: Author's computations based on After Access Surveys, RIA, 2017-2018.

Further, we conduct similar analyses to determine whether there are heterogeneous effects according to the firm's degree of informality and whether employers benefit differently from these uses than self-employed entrepreneurs. However, we do not find any significant differences in the magnitude of the effect of bilateral coordination on monthly sales across subgroups. Thus, all informal firms, regardless of their location, the gender of the entrepreneur at their head, their level of informality, or their size, benefit from using digital technologies for bilateral coordination with trading partners through a significant effect on their monthly sales. We conclude that there is no third-level digital divide for this specific usage among informal firms, the relative magnitude of the effect being similar, whatever their characteristics. Only the most successful informal firms, in the top quintile of the distribution of sales, appear to not significantly benefit from these basic uses of digital technologies, probably due to already lower external constraints and better market integration.

4.3 Pathways of the effect of digital bilateral market coordination on economic performance

Several pathways may be involved in the mediation process of the impact of digital bilateral coordination on the economic performance of informal firms. The characteristics of the firm's trading network could be among the channels, as indicated by the hierarchical regression analyses presented in Table 2, which show that the estimated effect of digital bilateral coordination on firm sales decreases when we account for these value-chain characteristics. Thus, we argue that two potential pathways can mediate the effect of the use of digital technologies for bilateral coordination with trading partners on informal firms' monthly sales: the accumulation of social capital and the expansion of market reach. To test these two potential pathways, we estimate simultaneous equation models using three-stage least squares (3SLS).

4.3.1 Strengthening the business network: social capital accumulation

By reshaping social interactions, digital technologies can affect the firms' social capital (Islam et al., 2018b). Indeed, reducing communication costs can increase the frequency of social interactions with trading partners, generating trust and norms of reciprocity (Molony, 2009). It can lead to better market coordination and lower transaction costs, which can benefit the economic performance of informal firms.

Table 6 presents the results for the social capital pathway with the monthly sales as a dependent variable in the main equation. Findings show that digital bilateral coordination significantly and positively affects the frequency of communication with suppliers and the probability of doing business with the most important trading partners over three years (Panel B, columns 2 and 3). Thus, informal firms continue to maintain stable business relationships, even though digital technologies allow them to diversify their sources of supply. In addition, digital bilateral coordination is associated with a higher reliability of the firm's most important suppliers and a greater likelihood of establishing relational

Table 6: Social capital pathway in the effect of digital bilateral coordination on firms' sales (3SLS results)

	Dependent Variable				
	(1)	(2)	(3)	(4)	(5)
Panel A: Eq. 1	Bilateral Coordination Dummy				
DT equipment rate of EA's households	0.186*** (0.054)	0.194*** (0.049)	0.192*** (0.053)	0.188*** (0.054)	0.180*** (0.054)
Bilateral coordination among firm's peers	0.246*** (0.049)	0.242*** (0.045)	0.234*** (0.049)	0.236*** (0.049)	0.226*** (0.049)
Panel B: Eq. 2	Reliability of suppliers	Frequent com. suppliers	Long relation with partners	Relational contracting with suppliers	Relational contracting with customers
Bilateral Coordination Dummy	0.204*** (0.077)	0.527*** (0.161)	0.170** (0.085)	0.211*** (0.079)	0.101 (0.159)
Panel C: Eq. 3	Log of monthly sales				
Reliability of suppliers	6.756** (2.936)				
Frequent communication with suppliers		2.724** (1.066)			
Long relation with partners			8.416* (4.539)		
Relational contracting with suppliers				6.205** (2.925)	
Relational contracting with customers					0.680 (1.060)
Observations	2530	2530	2530	2530	2530

Notes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. All the specifications include the full vector of control variables.
Source: Author's computations based on After Access Surveys, RIA, 2017-2018.

contracts with them (Panel B, columns 1 and 4). However, if the reduction in search costs seems to increase the incentives for engaging in relational contracting with suppliers, this is not the case for customers (Panel B, column 5). Overall, these results suggest that digital bilateral coordination increases the social capital of informal firms, as these four variables illustrate the intensity of social interactions, trust, and the norm of reciprocity in upstream relationships. It probably leads to better market coordination and reduced transaction costs when sourcing inputs. Specifically, relational contracts with suppliers are essential as they address market failures by providing credit or greater incentives to honor contracts (Fafchamps, 2006).

These four variables have a statistically significant and positive effect on informal firms' monthly sales (Panel C, columns 1, 2, 3, and 4), demonstrating that accumulation of social capital mediates a portion of the effect of digital bilateral coordination on the informal firms' economic performance. This finding is in line with Berrou and Combarrous (2012), who find that the strength of ties influences entrepreneurs' economic outcomes in the informal economy of Bobo-Dioulasso in Burkina Faso. In our context, this mediation effect seems to be mainly driven by better management of supply chains, as digital bilateral coordination does not seem to change the incentives to engage in relational contracts with customers (Panel B, column 5).

4.3.2 Reshaping the business network: market reach extension

Apart from strengthening the already existing trading network, digital technologies can reshape it by expanding the firm's market reach (Donner, 2006). Indeed, these technologies allow firms to communicate with remote interlocutors, thus expanding the geographical area where the firm can deploy its business network. By reducing search and communication costs, digital technologies can allow firms to expand their customer base, and maintain more relationships upstream of the production with suppliers. Further, digital technologies may also have the potential to enable informal businesses to access and maintain relationships within certain professional spheres that can only be reached through these communication channels.

Table 7 presents the results for the market reach pathway with the monthly sales as a dependent variable in the main equation. We find that digital bilateral coordination significantly increases the probability that informal firms have trading partners located further away than surrounding towns and villages, but also the probability that they have more than three suppliers (Panel B, columns 1 and 4). It is consistent with the reduction in search costs induced by digital technologies, which make it easier to find new suppliers through social networks and maintain more relationships at once (Rudder, 2020). While these uses do not significantly affect the likelihood of having businesses as customers (Panel B, column 2), user firms are more likely to have trading partners with a formal

Table 7: Market reach pathway in the effect of digital bilateral coordination on firms' sales (3SLS results)

	Dependent Variable			
	(1)	(2)	(3)	(4)
Panel A: Eq. 1	Bilateral Coordination Dummy			
DT equipment rate of EA's households	0.193*** (0.051)	0.187*** (0.054)	0.200*** (0.054)	0.157*** (0.053)
Bilateral coordination among firm's peers	0.236*** (0.047)	0.219*** (0.049)	0.218*** (0.049)	0.259*** (0.048)
Panel B: Eq. 2	Not local partners	Businesses as customers	Formal partners	More than three suppliers
Bilateral Coordination Dummy	0.185* (0.099)	-0.129 (0.134)	0.250* (0.142)	0.314*** (0.112)
Panel C: Eq. 3	Log of monthly sales			
Not local partners	8.095* (4.577)			
Businesses as customers		-0.902 (1.539)		
Formal partners			1.852* (1.069)	
More than three suppliers				4.084*** (1.394)
Observations	2530	2530	2530	2530

Notes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. All the specifications include the full vector of control variables.

Source: Author's computations based on After Access Surveys, RIA, 2017-2018.

status (Panel B, column 3). Digital bilateral coordination then contributes to the expansion of the market reach of informal firms through the multiplication of business relationships and the expansion of the geographical reach of the business network, but also through the possibility to access more formal professional spheres. Furthermore, having remote trading partners, more than three suppliers, or trading partners with formal status, has a statistically significant and positive effect on informal firms' monthly sales (Panel C, columns 1, 3, and 4). Thus, the extension of informal firms' market reach through access to less geographically concentrated trading partners, as well as the development of business networks, are involved in the mediation process of the effect of digital bilateral coordination on informal firms' economic performance.

5. Robustness checks

In this section, we conduct a series of robustness checks to address potential persistent sources of bias in the estimates presented in Section 4.1. In particular, we test the robustness of our instruments by addressing concerns about the excludability requirement. For this purpose, we re-estimate the model by including district or region fixed effects, and testing other instruments. Then, one of the instruments considered in the main results is measured at a different level in Kenya and Senegal than in other countries due to data availability issues. As this could lead to a bias in the estimates, we re-run the estimates without the samples from these two countries. Finally, we examine whether the estimates are robust when we consider alternative measures of economic performance and a more restrictive definition of informality. To this end, we repeat the analyses with two other variables of economic performance, and then consider only the most informal firms.

5.1 Excludability requirement: controlling for region and district fixed effects

Our identification strategy is based on the level of diffusion of digital technologies among households and firms in the geographical environment of the informal firms we are studying. Since the diffusion level of these technologies may be correlated with unobservable characteristics of the firm's environment that could also impact firm performance, we have included country-fixed effects, in addition to two proxies to control for the level of economic activity at the regional level: average night light luminosity and population density within a 5 km radius around the firm. Adding these control variables is relevant as it prevents a significant upward bias in the estimated coefficient of interest (Table 2). However, one could argue that country-fixed effects and these two proxies for the level of economic activity may be insufficient to ensure the validity of our instruments, especially with respect to the exclusion restriction.

To test the robustness of our results, we replace the country-fixed effects with 68 region dummies and then with 195 district dummies. It should allow better control of differences in economic activity between areas, which may correlate with the overall level of digital technology diffusion and the economic performance of informal firms. However, administrative subdivisions may differ between countries. For district fixed effects, we consider so-called districts for Ghana, Kenya, Tanzania, and Mozambique, states for Nigeria, and departments for Senegal. As a spurious correlation may occur between the instrument measured within 50 km of the firm and the district or regional dummy variables, we estimate the equation with both instruments and then with only the one measured at the EA level.

Table 8 presents the results of these robustness checks for the estimation of the effect of digital bilateral coordination on informal firms' monthly sales. Column 1 reports the results of the main specification in Section 4.1, including all control variables and country-fixed effects. When we replace these country-fixed effects by region dummies (column 2), the estimated coefficient of interest is significant and of a larger magnitude than in column 1. However, the estimation suffers from weak identification as the Kleibergen-Paap rank Wald F statistic becomes smaller than the threshold value of 10. This weak identification is due to the fact that one of the instruments has no significant effect on the endogenous variable. Indeed, the proportion of the firm's peers that use digital bilateral coordination in a radius of 50km does not significantly affect the endogenous variable in this specification. Column 3 presents the same specification as column 2, except that we only consider the instrument that appears to be valid. The estimated coefficient of interest remains significant, but the specification still suffers from weak identification, but to a lesser extent than in column 2.

We observe similar results for the district fixed effect specifications. In Panel A and column 4, the firm's peer instrument appears negatively correlated with the endogenous variable. We suspect a spurious correlation between the instrumental and endogenous variables when controlling for district fixed effect. Indeed, in the same district, the proportion of the firm's peers in a 50 km radius using digital bilateral coordination is

Table 8: Robustness checks including district or region fixed effects as control variables (2SLS results)

	Instrumental variable				
	(1)	(2)	(3)	(4)	(5)
Panel A: First-stage	Dependent variable: Bilateral coordination dummy				
DT equipment rate of EA's households	0.191*** (0.071)	0.250*** (0.083)	0.233*** (0.078)	0.526*** (0.161)	0.373*** (0.114)
Bilateral coordination among firm's peers	0.236*** (0.068)	-0.079 (0.094)		-1.243*** (0.311)	
Under-identification test	0.000	0.023	0.000	0.000	0.009
Weak instrument test	17.785	4.590	9.338	10.229	10.632
Over-identification test	0.951	0.119		0.036	
Endogeneity test	0.059	0.080	0.018	0.281	0.083
Panel B: Second-stage	Dependent variable: Log of monthly sales				
Bilateral coordination dummy	1.426** (0.612)	2.062** (1.036)	2.734** (1.182)	-0.099 (0.291)	1.883* (1.039)
R-squared	0.404	0.360	-0.084	0.318	0.137
Control variables					
Country fixed effects	Yes				
Region fixed effects		Yes	Yes		
District fixed effects				Yes	Yes
All other control variables included	Yes	Yes	Yes	Yes	Yes
Observations	2530	2530	2532	2530	2532

Notes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Standard errors clustered at the EA level.

Source: Author's computations based on After Access Surveys, RIA, 2017-2018.

arithmetically negatively correlated with the probability that the firm in question uses it. Hence, in the same district, firms that do not use digital bilateral coordination have a higher proportion of peers that use it compared to users. In column 5, we present the same specification as column 4, except that we only consider the instrument that appears to be valid. We find similar results that in column 1, confirming that our results are robust when we control for district-fixed effects, although the choice of instruments must be arranged.

5.2 Testing other instrumental variables

To test the robustness of our results to the choice of instrumental variables, we estimate the model described in Section 4.1 using a different pair of instruments. These are derived

from the initially selected instruments and are therefore highly correlated with them. However, they could be somewhat more exogenous. We replace the first instrument, the proportion of households owning digital technologies in the EA, with the average proportion of household survey respondents' five closest friends having a mobile phone at the EA level. This instrument may be more exogenous than the former as we do not only consider the digital technologies diffusion in the direct vicinity of the firm but in a larger geographical area. We replace the second instrument, the proportion of the firm's peers in a 50 km radius using digital bilateral coordination, with the proportion of the firm's peers for which digital technologies are the preferred mode of communication with trading partners in a 50 km radius. We do not ever consider the diffusion of such practices in the firm's business environment, but individual preferences that are potentially more exogenous.

Table 9 presents the results with this other pair of instrumental variables. We find similar results to those obtained with the original instrumental variables, as digital bilateral coordination appears to have a positive and significant effect on sales after controlling for endogeneity and confounding factors. The magnitude of the estimated coefficients is similar, although a bit larger. However, the pair of instrumental variables tested appears to be weaker than the original, according to the weak instrument and over-identification tests. The results of these robustness checks confirm that our instrumental variables satisfy the exclusion restriction. Indeed, our main results are robust to the introduction of district-fixed effects and to theoretically more exogenous instrumental variables.

5.3 Effects on other economic performance outcomes

In Section 4.1, we consider the firm's monthly sales as the main outcome variable. To test the sensitivity of our estimates to the choice of the outcome variable, we perform our estimation by considering the logs of the firm's value-added and net profit. While the value added is deduced from the monthly sales from which expenses of the business

Table 9: Robustness checks considering others instrumental variables (2SLS results)

	Instrumental variable			
	(1)	(2)	(2)	(4)
Panel A: First-stage	Dependent variable: Bilateral coordination dummy			
Rate of mobile phone ownership among HH survey respondent's friends	0.269*** (0.073)	0.329*** (0.081)	0.252*** (0.073)	0.228*** (0.070)
Proportion of firm's peers with ICT as preferred mode of communication	0.261*** (0.065)	0.286*** (0.069)	0.252*** (0.068)	0.236*** (0.065)
Under-identification test	0.000	0.000	0.000	0.000
Weak instrument test	18.890	17.785	13.536	12.492
Over-identification test	0.093	0.127	0.120	0.070
Endogeneity test	0.000	0.026	0.051	0.073
Panel B: Second-stage	Dependent variable: Log of monthly sales			
Bilateral coordination dummy	2.784*** (0.605)	1.836*** (0.550)	1.807*** (0.667)	1.643** (0.699)
R-squared	0.097	0.329	0.334	0.374
Control variables				
Controls for firm and entrepreneur	Yes	Yes	Yes	Yes
Country and sector fixed effects	Yes	Yes	Yes	Yes
Controls for area-level characteristics		Yes	Yes	Yes
Controls for DT equipment and other usage			Yes	Yes
Controls for trading partners characteristics				Yes
Observations	2530	2530	2530	2530

Notes: *p < 0.05, **p < 0.01, ***p < 0.001. Standard errors clustered at the EA level.

Source: Author's computations based on After Access Surveys, RIA, 2017-2018.

are subtracted, the net profit is independently estimated from the turnover. Results are reported in Table 10.

We find that using digital technologies for bilateral coordination with trading partners significantly increases the informal firms' value added by 187% on average. The magnitude of the effect is higher than the one estimated for monthly sales. We also find that digital bilateral coordination has a significant effect on the profit of informal firms, and that the estimated coefficient is similar in magnitude to that of sales. Hence, our results are robust regardless of the dependent variable chosen to measure firms' economic performance.

Table 10: Robustness checks considering other economic performance indicators (2SLS results)

	Instrumental variable	
	(1)	(2)
Panel B: Second-stage	Value-added	Net profit
Bilateral coordination dummy	1.868** (0.787)	1.503** (0.678)
R-squared	0.331	0.473
Control variables		
Controls for firm and entrepreneur	Yes	Yes
Country and sector fixed effects	Yes	Yes
Controls for area-level characteristics	Yes	Yes
Controls for DT equipment and other usage	Yes	Yes
Controls for trading partners characteristics	Yes	Yes
Observations	2336	2525

Notes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Standard errors clustered at the EA level.

Source: Author's computations based on After Access Surveys, RIA, 2017-2018.

5.4 Considering a more restrictive definition of informality

In our study, we restricted the sample to informal enterprises based on an informality index. This index considers five criteria related to the firm's registration, taxation, and accounting status. Enterprises meeting these five criteria were considered formal and excluded from the analysis. We test the robustness of our main results by considering a more restrictive definition of informality. We estimate our main model with a sub-sample that includes only firms that meet at most one criterion. Table 11 reports the results of this robustness check.

We find similar results in terms of magnitude and significance using this more restrictive definition of informality. The results show that digital bilateral coordination increases sales of firms that meet zero or one formality criterion by 139% on average. Thus, it confirms that our results are not driven by the upper tier of opportunity entrepreneurs who operate partially informally, which aligns with the findings from the quantile regression estimations (Table 3). Moreover, it highlights that the most vulnerable informal

firms, probably mostly subsistence entrepreneurs, benefit from digital inclusion through such basic uses of digital technologies.

Table 11: Robustness check considering a restrictive definition of informality (OLS and 2SLS results)

	OLS	Instrumental variable
	(1)	(2)
Panel B: Second-stage and OLS		
Dependent variable: Log of total monthly sales		
Bilateral coordination dummy	0.297*** (0.074)	1.391** (0.795)
R-squared	0.42	0.33
Control variables		
Controls for firm and entrepreneur	Yes	Yes
Country and sector fixed effects	Yes	Yes
Controls for area-level characteristics	Yes	Yes
Controls for DT equipment and other usage	Yes	Yes
Controls for trading partners characteristics	Yes	Yes
Observations	1896	1885

Notes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Standard errors clustered at the EA level.

Source: Author's computations based on After Access Surveys, RIA, 2017-2018.

5.5 Using a sub-sample of countries

Due to the inability to match EA identifiers between the business and household databases, one of our instruments is measured at a different level across countries. Indeed, the proportion of households owning digital technologies is measured at the EA level for Ghana, Nigeria, Tanzania, and Mozambique. In contrast, the instrument is measured at the district and urban/rural area for Senegal, and at the regional and urban/rural area for Kenya. It results in a loss of variance, which could bias the results. In order to test the robustness of our findings regarding this issue, we estimate the model without the observations of the Senegal and Kenya samples. Table 12 demonstrates that the estimates

are stable between the specification that includes the entire sample and the specification that excludes the Senegal and Kenya samples.

Table 12: Robustness checks comparing results with a sub-sample of firms (2SLS results)

	Instrumental variable	
	(1) Whole sample	(2) Sub-sample
Panel A: First-stage	Dependent variable: Bilateral coordination dummy	
DT equipment rate of EA's households	0.191*** (0.071)	0.168* (0.089)
Bilateral coordination among firm's peers	0.236*** (0.068)	0.207** (0.082)
Under-identification test	0.000	0.003
Weak instrument test	17.785	9.337
Over-identification test	0.951	0.652
Endogeneity test	0.059	0.091
Panel B: Second-stage	Dependent variable: Log of monthly sales	
Bilateral coordination dummy	1.426** (0.612)	1.353** (0.676)
R-squared	0.404	0.367
Control variables		
Controls for firm and entrepreneur	Yes	Yes
Country and sector fixed effects	Yes	Yes
Controls for area-level characteristics	Yes	Yes
Controls for DT equipment and other usage	Yes	Yes
Controls for trading partners characteristics	Yes	Yes
Observations	2530	1696

Notes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Standard errors clustered at the EA level.

Source: Author's computations based on After Access Surveys, RIA, 2017-2018.

6. Conclusion

The persistence of informality remains a major feature of the productive structure of developing countries, particularly in sub-Saharan Africa. Facing significant external constraints and market frictions, some argue that these informal firms should benefit from the rapid proliferation of digital technologies (Choi et al., 2020; Ngumkeu and Okou, 2021). While the adoption of advanced technologies or services, such as the internet and mobile money, is still in its early phase or reflects country-specific contexts, informal

firms primarily use digital technologies for what they fundamentally are: information and communication technologies. Indeed, they mainly use these technologies as a mode of communication within their value chain, potentially benefiting from a significant reduction in transaction costs and improved market coordination (Aker and Blumenstock, 2015).

In this chapter, we provide further robust evidence of the structural effect of digital technologies usage on the economic performance of non-farm informal firms in sub-Saharan Africa. After controlling for endogeneity and a large set of confounding factors using an instrumental strategy, we find that sales, value-added, and net profit are significantly higher for informal businesses that use digital technologies to communicate with their trading partners than non-users. Our findings confirm the overall enhancing effect of access to and use of digital technologies on informal firms' performance documented in the literature, and specifically the central role of bilateral coordination practices in the context of Africa (Eekhout et al., 2022; Berrou et al., 2020). While the spread of advanced uses such as mobile money and the internet is promising, we show that the most basic communication uses are the first step in building a better business environment for small firms. Indeed, our findings show that digital bilateral coordination affects informal firms' sales by significantly reshaping their trading network. On the one hand, we show that, as on agricultural markets (Tack and Aker, 2014; Bergquist et al., 2021), non-farm informal firms may benefit from digital technologies through better market access. Indeed, user firms are likely to have more suppliers, formal partners, and trading partners located further away than the surrounding villages and towns than non-users. On the other, firms implementing digital technologies in their professional interactions appear to have greater strength of ties in their upstream value chain (Berrou and Combarrous, 2012), inducing a reduction in transaction costs and better access to relational contracting (Rudder, 2020).

All informal firms appear to benefit to the same extent from this usage, regardless of the entrepreneur's gender, the firm's location, its level of informality, or its size, highlighting the absence of a third-level digital divide for this usage (Scheerder et al., 2017). Our

quantile regression estimates show that even the most vulnerable informal firms in sub-Saharan Africa may benefit from adopting such basic uses of digital technologies. Given the significant inequalities in access and usage observed within this population in Chapter 1, it shows that once the initial barriers to usage have been overcome, all informal firms can benefit from the most basic uses of digital technologies to the same relative extent. It supports that public policies should seek to overcome barriers to access and use of digital technologies by achieving universal access and affordability of digital devices and services. In addition, interventions aiming to improve small firms' productivity rarely include technology adoption or digital skills training (Quinn and Woodruff, 2019), despite the accumulation of empirical evidence on the enhancing welfare effects of the adoption of such technologies (Bahia et al., 2023). As the uneven adoption of digital technologies by small firms according to their characteristics is a new source of economic inequalities, we argue that such policy interventions should specifically target the lower and intermediate fringes of the informal sector, which comprise the most digitally excluded firms and entrepreneurs.

Finally, we identify some limitations of our empirical study that should be addressed in future research. First, we are using data that is not nationally representative of the informal sector in each of the six sub-Saharan countries, although the firms have been randomly selected. Although it threatens the external validity of our findings, we can reasonably argue that this is not a major issue, as our results align with the empirical evidence on the positive effects of digital technologies on informal firms' productivity in the context of sub-Saharan Africa (Eekhout et al., 2022; Esselaar et al., 2006; Danquah and Owusu, 2021). However, there is likely some heterogeneity in the relationship studied across countries, due to specificities of their productive structure or the stage of diffusion of digital technologies, which future research could uncover through case studies. In our case, robustness checks show that our main result is robust when we exclude the samples from Senegal and Kenya, the two countries where digital bilateral coordination is most used by informal businesses. Second, the data does not allow us to go beyond the binary notion of performing digital bilateral coordination tasks.

Considering the multidimensionality of usage could have revealed differentiated effects according to the intensity or the purposes of these coordination practices. Specifically, our endogenous variable includes both bilateral coordination with suppliers and customers. The strong correlation between these two coordination channels does not allow us to empirically investigate the specific effect of downstream or upstream coordination on the performance of informal firms. Finally, finding instruments that perfectly satisfy the excludability requirement and controlling for all major confounding factors remains challenging. In this context, experimental approaches would be relevant to better identify the causal relationships between the use of digital technologies and informal firms' economic performance.

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Chapter 3

Evolution of Mobile Technologies

Uses and Performance of Small Firms:

Panel Evidence from the Informal

Sector of Dakar

Abstract.

This chapter investigates how professional uses of mobile technologies are associated with the economic performance of small informal firms. Using panel data collected from a sample of 304 informal entrepreneurs in the Dakar region of Senegal, we develop a multidimensional measure of mobile technologies uses, including 32 variables that indicate the purposes for which informal entrepreneurs use these technologies, how they accomplish these tasks, and at which intensity level. Panel data indicates that mobile technologies appropriation at baseline and subsequent evolution are significantly associated with firms' dynamics. Our analysis also provides robust evidence that variation in mobile technologies appropriation explains differences in performance across small informal firms. Specifically, we find that intensity of use is particularly associated with firms' sales, while value-added increases with the number of tasks implemented. Further, in addition to improving firms' technical efficiency, we find that higher appropriation levels of mobile technologies are associated with higher capital accumulation and innovation capacity, as well as a lower level of informality.

1. Introduction

In sub-Saharan Africa, most firms remain self-employed business owners or small businesses with few employees, which predominantly operate in the informal sector (Hsieh and Olken, 2014). Despite their important contribution to employment and income generation, these small firms have long been recognized to have low average productivity levels (La Porta and Shleifer, 2014). In addition, significant differences in performance persist among them. A large strand of experimental literature has studied this heterogeneity in performance, revealing important constraints faced by small firms (Quinn and Woodruff, 2019). Besides important constraints in access to factors of production, notably low ability to invest in fixed and variable capital despite significant returns to capital investment (Fafchamps et al., 2014; Grimm et al., 2012), firm technology has been pointed out as a large source of total factor productivity heterogeneity (Bloom et al., 2016). In developing countries, it primarily relates to the firm's individual manager or owner entrepreneurial ability, commonly assessed through management or business practices (McKenzie and Woodruff, 2017).

Recent evidence shows that professional usage of digital technologies, especially mobile technologies, may also explain a significant part of productivity differences observed between small firms (Nguimkeu and Okou, 2021). Indeed, the rapid diffusion of digital technologies since the start of the millennium constitutes a significant technical change in the firms' business environment. In sub-Saharan Africa, mobile technologies are pervasive and subject to significant technological dynamism, with product and service innovations occurring at a high pace (GSMA, 2022). Thus, mobile technologies can be considered general-purpose technologies (Bresnahan and Trajtenberg, 1995), that can provide a wide range of tangible economic benefits to small businesses.

The literature has highlighted a broad set of channels and mechanisms through which small firms may benefit from the use of digital technologies. First, mobile telephony and the internet improve information dissemination by reducing communication and information search costs (Goldfarb and Tucker, 2019). This improved access to

information reduces overall uncertainty and increases access to knowledge, from which small firms may benefit through more efficient economic decisions (Leff, 1984). By stimulating information flows, digital technologies also have the potential to improve market coordination with the firm's partners. It can improve the sourcing of goods and raw materials from suppliers (Jagun et al., 2008), and expand their customer base through improved information on demand characteristics and new sales channels (Sife et al., 2010). Second, as financial inclusion remains low in developing countries (Demirguc-Kunt et al., 2018), small firms can largely benefit from financial technology innovations such as mobile money. Such services enable a reduction in transaction costs along with improvements in security and liquidity, which may facilitate trade by making existing transactions more efficient, and enabling transactions that would never have existed otherwise (Suri, 2017). In addition, mobile money services can also benefit small businesses in terms of financial inclusion. In the context of imperfect capital markets, access to capital is identified as one of the major constraints faced by small firms (Grimm et al., 2011a). While most have limited or no access to bank credit, mobile money provides access to a broader range of external sources of finance, such as family or business networks, both locally and across international boundaries (Beck et al., 2018). Mobile money is also a key financial innovation that offers the possibility to store or save money in security, thus enhancing the ability of micro-entrepreneurs to prevent theft, improve the management of their finance and their reinvestment capacity (Riley, 2022; Jack and Suri, 2014; Batista and Vicente, 2020; De Mel et al., 2022). While the above usage requires widespread access to and adoption of digital technologies among external partners, micro-entrepreneurs can also rely on digital technologies to improve the internal management of their businesses. More advanced devices than cellular phones, such as smartphones and computers, provide access to built-in and specific applications that can help them improve their inventory management, record keeping, financial planning, or human resources management (Atiyas and Dutz, 2021).

Hence, digital inclusion of small firms may generate significant productivity gains (Hjort and Tian, 2023). Digital technologies have the potential to improve factor productivity, by

increasing production from the same quantities of inputs. In addition, they can help small firms overcome some of the constraints they face, potentially reducing input prices and cost of finance, for example. The empirical literature confirms the existence of such an association between the usage of digital technologies and firms' economic performance at the macro and firm-levels in the context of developed countries, with a large positive impact of investments in digital technologies on productivity (Goldfarb and Tucker, 2019; Cardona et al., 2013). In emerging and developing countries, studies examining the role of digital technologies in business performance are mainly focused on formal firms (Commander et al., 2011; Motohashi, 2008; Cariolle and le Goff, 2023; Paunov and Rollo, 2016). However, some empirical studies have demonstrated a significant and positive association between small informal firms' uses of digital technologies and economic performance in sub-Saharan Africa (Esselaar et al., 2006; Danquah and Iddrisu, 2018; Danquah and Owusu, 2021; Atiyas and Dutz, 2021, 2023; Berrou et al., 2020; Eekhout et al., 2022). Although these few empirical studies confirm that digital technologies hold some potential to spur informal firms' performance, more evidence is needed to orientate new forms of small firms policy interventions that actually focus on formalization assistance and business training (Quinn and Woodruff, 2019). We argue that the complexity of the digital inclusion process requires going beyond material access and adopting quantitative measures that consider the multidimensionality of effective usage (Donner, 2015; Ragnedda, 2019; Sharp, 2022). Indeed, different forms of technology appropriation are likely to emerge, significantly accounting for differences in economic performance among small informal firms (Berrou et al., 2020; Eekhout et al., 2022).

In this chapter, we investigate the relationship between professional usage of digital technologies and small firms' economic performance using panel data collected among small informal firms from Dakar (Senegal) in 2017 and 2019. These surveys constitute an original and representative panel data of an urban informal sector with a large set of standardized questions about digital technologies appropriation among informal entrepreneurs. Our measure of professional usage of digital technologies is based on responses to 32 questions collected in both survey waves. These questions primarily focus

on the use of mobile technologies, allowing us to observe for what purposes informal entrepreneurs use these technologies, how they accomplish these tasks, and at which intensity level. We measure the overall level of mobile technologies appropriation by computing the proportion of the 32 uses that each business implements, and consider each specific dimension of the entrepreneurs' technology appropriation by constructing three additional subcomponent scores that capture the number of tasks, the range of features, and the intensity of use.

Using these different measures and the panel data, we first examine how stable mobile technologies usage is over a two-year period, and to which extent these professional uses are associated with firms' survival and subsequent sales growth. Second, we analyze whether the usage of mobile technologies is associated with higher firm economic performance in the informal sector of Dakar, considering monthly sales and value-added as dependent variables. We estimate panel data models with fixed effects (FE) estimator to address the omitted variable bias likely to occur in the relationship between usage of digital technologies and firms' performance. Third, we explore different channels through which digital technologies may affect small firms' economic performance. We argue that digital technologies have the potential to overcome some constraints faced by small firms in sub-Saharan Africa and thus indirectly affect their economic performance. Using our panel data, we further estimate the association between digital technologies and the following intermediate outcomes: registration and tax payment status, access to credit, capital accumulation dynamics, and innovation behaviors. We argue that digital technologies can affect these intermediate outcomes by modifying the economic costs faced by informal firms, and the information they can access.

We find that the digitalization of informal activities in the Dakar region has made significant progress between 2017 and 2019, with an overall increase in smartphone ownership and diffusion of bilateral coordination and mobile money usage. However, we observe contrasting trends in the diffusion of text messaging, internet use, and the adoption of digital internal management practices. Panel data also shows that mobile technologies appropriation at baseline and subsequent evolution are significantly

associated with firms' dynamics. On the one hand, two-year firm's survival is significantly associated with the range of bilateral coordination uses at baseline, suggesting that better market coordination with trading partners helps predict informal firms' survival. On the other, we find no evidence that professional usage of mobile technologies at baseline is significantly associated with subsequent firms' sales growth. However, we find that firms that have improved their overall use of mobile technologies over the period have significantly higher sales growth rates than firms whose overall score has declined or stagnated. This association between mobile technologies usage and firms' economic performance is confirmed by estimates from the panel model with fixed effects. Findings show that the digitalization of informal firms' business operations is associated with higher monthly sales and value-added. While these associations are both driven by the number of tasks and intensity of usage, different patterns appear according to the dimension of economic performance under consideration. While sales are primarily associated with the daily use of bilateral coordination features to communicate with trading partners, firms' value-added is mainly associated with mobile money usage. Finally, we identify some channels through which mobile technologies usage may affect small firms' performance. Significant associations are found between specific functions of mobile technologies and firms' formal status, capital accumulation process, and innovation behaviors.

The remainder of this chapter is organized as follows. Section 2 describes the panel data survey and presents some interesting patterns in the dynamic of the informal sector of Dakar. Section 3 details our conceptual approach to measuring professional usage of mobile technologies and the empirical strategy. Section 4 presents the findings related to the statistical association between mobile technologies usage and firms' dynamics, economic performance, and intermediate outcomes. Finally, we discuss the results and conclude in Section 5.

2. Data and descriptive statistics

2.1 The panel survey

The panel data used in this chapter is drawn from a research program coordinated by Jean-Philippe Berrou from Les Afriques dans le Monde (LAM)¹ and funded by the research department of Orange Innovation, which aimed at providing new insights on access to and use of mobile technologies by informal entrepreneurs in the Dakar region of Senegal. The panel data comprises two waves of a non-farm business establishments survey collected by the CRDES² of Dakar, the baseline taking place in 2017 and the second wave in 2019.

The baseline survey followed the national definition of informality (ANSD, 2016), considering that production units without a registration number³ or not complying with the official West African accounting system (SYSCOA) are informal. The sampling method was based on quotas, respecting gender distribution of the head of these informal businesses, location by department⁴, and economic sectors (industry, trade, and services)⁵. In the absence of a sampling frame, the Politz method (or random walk method) was adopted to avoid any risk of selection bias and reinsert randomness into the quota sampling. The baseline sample is then composed of 500 informal enterprises, representative of the fixed and visible non-agricultural informal sector of the Dakar region⁶.

Collecting panel data on informal enterprises is an ambitious task and, so far, rarely achieved in developing countries⁷. Their vulnerability due to lack of registration, low

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³The registration criteria is the National Identification Number of Enterprises and Associations (NINEA).

⁴Before 2021, the Dakar region included the departments of Dakar, Guédiawaye, Pikine, and Rufisque. Then the municipality of Keur Massar in the department of Pikine became a department.

⁵The quotas were established following two surveys previously conducted by ANSD, namely, the 2016 “Enquête Nationale sur les Unités de Production Informelles au Sénégal” (ENUPIS) and the 2012 “Enquête de Suivi de la Pauvreté au Sénégal” (ESPS).

⁶Unlike mixed surveys that identify informal activities from household surveys, our establishment survey does not include some of the most vulnerable informal activities such as street vendors, or invisible activities like those operating at home behind closed doors.

⁷See McKenzie and Paffhausen (2019) for a review of existing evidence.

productivity, and higher economic, social, and institutional constraints (La Porta and Shleifer, 2014; Grimm et al., 2011b; Gutierrez and Rodriguez-Lesmes, 2023) may induce lower survival rates than formal firms, but also increased sectoral and geographical mobility. Then, as a first step, the second wave survey aimed to determine whether the 500 informal production units surveyed in 2017 were still in operation in 2019, considering that it is the case if they still had the same main activity description. Therefore, establishments that moved, or changed their main manager or owner, were included in the sample as long as they carried out the same activity as in the first wave.

Finding the respondents from the first wave two years later was a real challenge, especially as this second survey was not planned in 2017, which limited the collection of data that could facilitate follow-up⁸. The first phase of the tracking process relied mainly on the mobile phone numbers of entrepreneurs collected in the baseline survey and was rather successful as 74% of the respondents could be reached. Therefore, the second stage of the follow-up aimed to find the remaining 130 businesses, using the limited information available. Enumerators and the supervisory team made considerable efforts to minimize sample attrition between the two survey waves, by attempting to locate all businesses that were initially unreachable by telephone in the field. After two weeks, the field follow-up resulted in 51 additional businesses being found. Thanks to this intensive tracking, the pure attrition rate is low, as we have no information for only 79 businesses of the baseline sample (15.8%) (Table 1). There are 58 businesses that stopped their activity between 2017 and 2019, representing a mortality rate of 11.6%. It is a lower-bound estimate of business mortality, as many businesses that could not be reached by telephone or in the field are also likely to have ceased activity. Then, the real mortality rate for 2017-2019 is between 11.6% and 27.4%. The final component of the attrition process includes firms that still exist but refused to respond or were unavailable during the survey period (3.6% and 3.4%, respectively).

⁸Only the identity of the entrepreneur, his or her telephone number, the type of activity conducted, the name of the establishment if any, and imprecise address information were available. No GPS data on the location of the business was collected in 2017, and the location of the respondent's household is unknown due to the establishment survey frame.

Table 1: Attrition process over the period (2017-2019)

	Baseline sample	Business closures	No information	Refusal/absent	Owner changed	Total attrition
N	500	58	79	35	24	196
%	100	11.6	15.8	7	4.8	39.2

Source: Author's computations.

As a result, 328 businesses surveyed in 2017 were also surveyed in the second wave. Of these, 24 are no longer run by the same entrepreneur as in the first survey wave in 2017. As we aim to observe the evolution of entrepreneurs' usage of digital technologies, we decide to exclude these few observations from the analysis. Hence, after balancing the panel between years, we obtain a final sample of 608 informal businesses, i.e., 304 per year. The harmonization of the questionnaire between the two survey waves allows us to observe the evolution of their economic performance, mode of operation, capital accumulation, and employment. In addition, it constitutes the first representative panel data of an urban informal sector in West Africa, which allows us to observe the diffusion of digital technologies among informal entrepreneurs in detail.

2.2 Determinants of attrition and mortality

Table 2 shows pure attrition, mortality, and total attrition rates by entrepreneur and firm characteristics. Overall, the attrition is significantly and positively correlated with some socio-economic and demographic characteristics of the entrepreneurs that may accentuate their mobility in the labor market, such as level of education, age, or place of birth. Indeed, we observe higher attrition rates for entrepreneurs not born in the Dakar region, potentially because of higher spatial mobility and vulnerability due to a less locally embedded social network. The education level of entrepreneurs is also significantly correlated with the level of total attrition, showing a U-shaped relationship as entrepreneurs with no education and entrepreneurs with tertiary education have the highest total attrition rates. Interestingly, low levels of education are positively correlated with not being found at the follow-up, while tertiary education is positively correlated with mortality rates. Furthermore, the age of the entrepreneur is positively correlated

with the firm's chances of survival between the two surveys, with younger entrepreneurs having higher levels of attrition than older ones. The gender of the entrepreneur is only correlated with the level of mortality rates, as female-led firms have significantly higher mortality rates. Regarding firm characteristics, firms with more than two workers have lower attrition rates than others. It suggests that the larger the informal enterprises, the less vulnerable they are. Of course, the direction of causality can be reversed, with the least vulnerable firms having the capacity to grow over time, which is confirmed by a significantly negative correlation between firm age and attrition levels. In addition, trade activities and those operating on the street exhibit a higher total attrition rate compared to others, suggesting that petty trading activities from the region of Dakar have a lower likelihood of surviving during the observed two-year period.

Since the attrition process is correlated with some entrepreneur and firm characteristics, one may be concerned about a potential bias in the results of further estimations due to non-random attrition. To check for the randomness of the total attrition process, we first use an attrition probit (Fitzgerald et al., 1998) to estimate the determinants of total attrition in 2019, as a function of baseline observable characteristics (Table 3)⁹. We find that businesses run at baseline by entrepreneurs who were not born in the Dakar region and who have tertiary education are significantly more likely to be affected by future attrition between the two survey waves. The model also confirms that young entrepreneurs are less likely to be surveyed in 2019 than older ones. Finally, trade activities have a higher probability of being concerned by attrition than manufacturing activities, while the same is observed for firms located in the department of Pikine compared to those located in the department of Dakar. Although these characteristics are significant predictors of attrition, the sample of firms surveyed again in 2019 still respects the quotas defined in 2017, either at the level of the entrepreneurs' gender, the department, the industry, or the intersection between industry and department. Thus, the balanced panel of 304 informal enterprises remains representative of the informal sector of the Dakar region with respect

⁹We also present in Table 3 the estimates of the binary response models considering pure attrition (not being found during the follow-up) and mortality (declared cessation of activity) as dependent variables.

Table 2: Attrition rates by firm and entrepreneur characteristics (%)

Entrepreneur	No info	Mortality	Total	Firm	No info	Mortality	Total
Gender				Sector			
Female	15.0	14.5	39.7	Manufacture	14.1	5.6	31.7
Male	16.4	9.4	38.8	Service	18.2	11.4	38.1
				Trade	14.8	16.5	46.2
Born in Dakar				Age of firm			
Yes	12.8	8.4	32.2	Less than 4	22.4	15.2	50.4
No	19.4	15.4	47.6	Between 4 and 7	16.9	14.7	39.7
				Between 7 and 15	13.9	8.7	40
Level of education				15 and more	9.7	7.3	26.6
No education	25.3	10.1	44.3	Size			
Koranic school	17.0	10.2	37.3	Self-employed	18.6	12.3	41.8
Primary	13.0	8.1	34.2	1 or 2 workers	16.7	14.0	43.3
Lower secondary	10.3	14.7	38.2	3 workers or more	10.0	7.7	30
Upper secondary	15.4	15.4	40.4				
Tertiary	13.6	31.8	68.2	Wage worker			
Illiterate				Yes	16.3	11.1	42.3
Yes	19.2	9.3	40.7	No	15.7	13.0	38.2
No	14.0	12.8	38.4				
Age				Type of location			
Less than 30	24.8	18.1	54.1	Building	16.6	10.3	39.9
Between 30 and 35	18.7	9.7	42.5	Home	11.6	10.1	33.3
Between 35 and 45	8.0	8.9	29.5	Market	13.4	13.4	36.6
More than 45	9.9	9.1	28.1	Street	20.5	13.6	45.5
				Other	23.3	13.3	50
Wage experience				Registered			
Yes	13.0	16.3	34.8	Yes	18.1	9.7	41.7
No	16.4	10.5	40.2	No	15.4	11.9	38.8
Total	15.8	11.6	39.2				

Source: Author's computations.

to the quotas defined during the baseline survey. Moreover, professional uses of mobile technologies at baseline do not predict significantly future attrition.

To further check for the randomness of the total attrition process, we conduct Beckett, Gould, Lillard, and Welch (BGLW) tests (Beckett et al., 1988). This test consists of regressing an outcome variable observed in the baseline survey on individual-level explanatory variables, a dummy attrition variable, and the dummy attrition variable interacted with the other explanatory variables. We perform this test for three different outcome variables: the logarithm of monthly sales, the logarithm of monthly value-added, and the logarithm of monthly profit. We include all the control variables used in our main analysis, including entrepreneur and firm characteristics, as well as the use of

Table 3: Attrition probit estimation

	(1) Total attrition	(2) Mortality	(3) No info
Woman	0.061 (0.046)	0.090*** (0.032)	0.022 (0.034)
No education (Ref.)	-	-	-
Primary	-0.041 (0.060)	-0.039 (0.037)	-0.078 (0.049)
Secondary	0.003 (0.070)	0.030 (0.048)	-0.078 (0.053)
Tertiary	0.252** (0.109)	0.189* (0.099)	-0.086 (0.082)
Age	-0.051*** (0.011)	-0.012 (0.008)	-0.023** (0.009)
Age (squared)	0.001*** (0.000)	0.000 (0.000)	0.000** (0.000)
Born in Dakar	-0.113** (0.044)	-0.080*** (0.029)	-0.035 (0.035)
Literate	-0.005 (0.058)	0.042 (0.040)	0.006 (0.043)
Baseline log(Sales)	0.001 (0.020)	-0.002 (0.011)	0.001 (0.016)
Operate at home	-0.063 (0.061)	-0.013 (0.039)	-0.047 (0.048)
Registered (NINEA)	0.067 (0.065)	-0.035 (0.048)	0.094* (0.051)
Keep accounts	-0.008 (0.046)	-0.050 (0.031)	0.057* (0.034)
Bank account	0.042 (0.048)	0.005 (0.031)	-0.010 (0.039)
Access to electricity	0.003 (0.052)	-0.026 (0.033)	-0.012 (0.041)
Firm's age	-0.007 (0.006)	-0.000 (0.005)	-0.001 (0.005)
Firm's age (squared)	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)
Self-employed (Ref.)	-	-	-
Between one and three workers	0.054 (0.050)	0.042 (0.033)	-0.008 (0.042)
At least four workers	0.044 (0.069)	0.043 (0.051)	-0.076* (0.044)
Manufacturing (Ref.)	-	-	-
Service	0.031 (0.055)	0.046 (0.031)	0.006 (0.045)
Retail/Trade	0.116** (0.055)	0.102*** (0.033)	-0.032 (0.043)
Dakar (Ref.)	-	-	-
Guédiawaye	-0.096 (0.073)	0.041 (0.051)	-0.084* (0.047)
Pikine	-0.178*** (0.053)	-0.030 (0.032)	-0.036 (0.041)
Rufisque	-0.104 (0.090)	0.022 (0.074)	-0.020 (0.067)
Mobile total score	-0.134 (0.130)	0.027 (0.079)	-0.008 (0.105)
Smartphone	-0.051 (0.053)	-0.006 (0.034)	-0.065 (0.040)
Observations	500	500	500

Notes: Average marginal effects from probit estimations. Robust standard errors are in parentheses. *p < 0.05, **p < 0.01, ***p < 0.001.

Source: Author's computations.

digital technologies. To determine whether the coefficients of each explanatory variable are different across informal businesses that are in the panel or are part of the attrition process, we compute F-tests of the joint significance of the attrition dummy and the interaction control variables on all outcomes of interest. For all outcome variables, we cannot reject the null hypothesis at the highest levels of significance, confirming that attrition in the period between the two survey waves is random¹⁰.

2.3 Dynamics of the informal sector of Dakar

Table 4 briefly describes the 304 entrepreneurs surveyed during the two waves. Most of them were born in Senegal (96%), and a significant proportion are from regions other than Dakar. Less than half of businesses are run by a woman, and entrepreneurs are on average 39 years old. Most entrepreneurs are educated with at least primary education, but more than a third of them are illiterate. Only 26% have completed secondary school. The average business had been in operation for 11 years, and the large majority was started by the respondent (91%). The firms in our sample carry out a wide range of activities, almost equally distributed between the retail, service, and manufacturing sectors.

Table 4 also presents firms' and entrepreneurs' time-variant characteristics, which allow us to observe the dynamic of the informal sector of Dakar over a two-year period. At baseline, only 14% of firms have a NINEA (registration number), and any keep accounts that comply with the accounting system standards in force in Senegal. Therefore, all the activities surveyed are considered informal using the national criteria of informality. However, this does not prevent more than two-thirds of firms from paying formal taxes. Some firms pay turnover tax, a global progressive tax estimated from self-declared statements called "Contribution Globale Unique" (CGU). Many other firms are subject to business tax in the form of an annual lump based on the observable characteristics of each establishment and collected more often by local agents on-the-spot¹¹. No significant formalization process can be observed between 2017 and 2019. Few firms obtained a

¹⁰See Baulch and Quisumbing (2011) for more details on attrition probits and BGLW tests.

¹¹Several business taxes exist, such as market, street occupation, or city fees, and can be added together.

Table 4: Entrepreneurs and firms characteristics

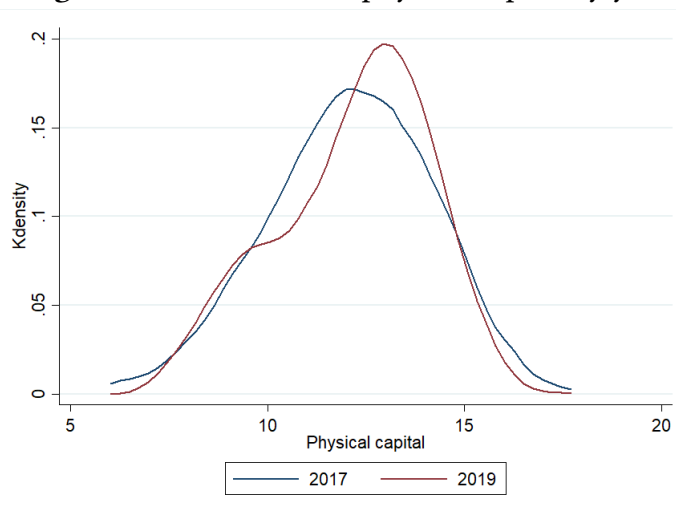
	2017	2019	<i>t</i> -Test
Owner's characteristics			
Female	0.42	0.42	1.00
Owner's Age	38.7	40.7	0.02**
Born in Dakar	0.61	0.61	1.00
Literate	0.66	0.66	1.00
No education	0.39	0.39	1.00
Primary	0.35	0.35	1.00
Secondary	0.24	0.24	1.00
Tertiary	0.02	0.02	1.00
Firm's characteristics			
Firm's age	11.2	13.2	0.01***
Manufacturing	0.32	0.32	1.00
Service	0.36	0.36	1.00
Retail/Trade	0.32	0.32	1.00
Registered (NINEA)	0.14	0.19	0.06*
Pay formal taxes	0.73	0.71	0.72
Keep accounts	0.42	0.46	0.41
Bank account	0.48	0.48	0.94
Indoor premises	0.44	0.40	0.29
Indoor premises (at home)	0.15	0.13	0.35
Market activity	0.28	0.34	0.11
Street	0.08	0.10	0.32
Electricity access	0.67	0.69	0.66
Water access	0.41	0.50	0.03**
Dakar	0.36	0.37	0.87
Guédiawaye	0.10	0.10	0.89
Pikine	0.45	0.44	0.81
Rufisque	0.09	0.10	0.78
Economic performance			
Self-employed	0.42	0.44	0.68
Between one and three workers	0.35	0.34	0.67
At least four workers	0.23	0.23	1.00
At least one wage worker	0.23	0.25	0.64
Monthly worker remuneration	118348	115851	0.01**
Physical capital stock	539414	496853	0.07*
Monthly sales	404331	398975	0.35
Monthly value-added	221754	147835	0.14
Monthly profits	152683	92256	0.17

Notes: We report the trimmed mean (trimmed by 5%) for monetary variables which are expressed in real XOF. However, *t*-Test consider mean values for each year. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

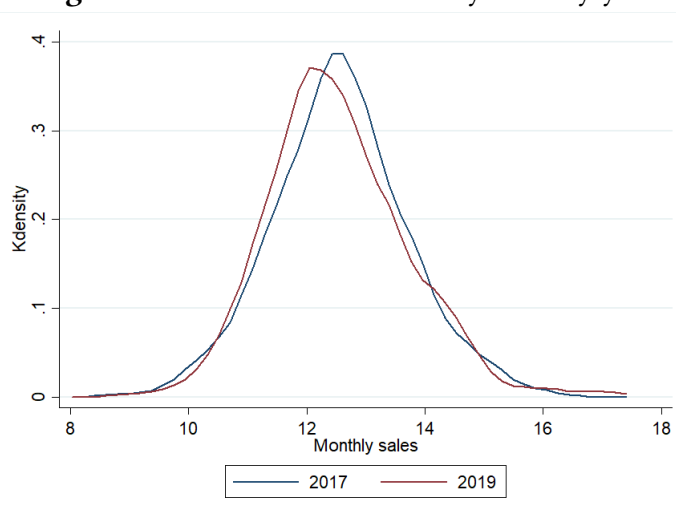
Source: Author's computations.

NINEA registration number (10%), while others informalized, as they had an identification number in 2017 but not in 2019 (4%). Similarly, no firm has begun to produce accounts that comply with national standards, and the same proportion of firms pay formal taxes over the period. We observe the same trend in terms of financial inclusion, with the proportion of bank account ownership remaining similar between the two survey waves. This conceals individual phenomena of bank account opening and closure, both of similar magnitude (14% for each).

Such structural stability is also observed regarding other characteristics of informal firms in our sample. Most businesses are located in indoor premises (59%), with the remainder operating on the street, in more precarious premises, or stalls. Although almost 20% of entrepreneurs changed their business location or premises over the period, most keep a similar type of site. Access to public services remained relatively stable, with a slight increase in access to water on the firm's premises. In 2017, the mean firm had a physical capital stock of just over 540,000 XOF (approximately 2,188 USD). Despite a slight decrease in the mean value of business-related assets in 2019, the kernel densities of physical capital distribution for each year show a significant capital accumulation process among informal firms in our sample between the two years (Figure 1). It is consistent with the fact that 63% of firms surveyed in 2019 report having professionally reinvested their profits over the past two years. Between the two surveys, almost half of the firms report that they have made replacement investments, 61% have made investments to increase the productive capacity of their business, and 14% have invested in another business activity. In parallel with such a capital accumulation process, employment in the informal sector is relatively stable, with the average firm having two workers in both years. However, about 40% of firms are self-employed workers with any employee, while 23% of firms have at least four workers. In both years, one-quarter of firms have one wage employee or more, and firms that hire workers pay an average labor cost of around 115,000 XOF per month (approximately 466 USD).

Figure 1: Distribution of physical capital by year

Source: Author's computations.

Figure 2: Distribution of monthly sales by year

Source: Author's computations.

At baseline, the mean firm had monthly sales of about 400,000 XOF (approximately 1,621 USD), value-added of 220,000 XOF (approximately 891 USD), and profits of 150,000 XOF (approximately 608 USD)¹². Overall, the average value of monthly sales stagnated (Figure 2) while the average value-added decreased between the two surveys. However,

¹²These figures are consistent with data from the Recensement Général des Entreprises (RGE) conducted in Senegal in 2016 (ANSD, 2017). According to the author's computations, the informal businesses in the Dakar region surveyed during the RGE have an average monthly turnover of around 500,000 XOF. Although these figures seem high, our findings and those of the RGE are based on a sampling of visible and fixed informal activities. It is, therefore, not representative of the lower and most vulnerable fringes of Dakar's informal sector.

in 2019, 41% of entrepreneurs consider that their business income has increased since the baseline, while 29% report the opposite, revealing heterogeneous trends in performance evolution. Hence, despite overall structural stability in terms of operating conditions, employment, legal status, access to infrastructure, and financial inclusion, heterogeneous performance dynamics seem to be at work during these two years in the informal sector of Dakar.

3. Empirical strategy

3.1 Defining and measuring professional usage of mobile technologies

In order to go beyond the possession of ICT devices and to observe the effective use of these technologies, specific modules were included in the two waves of the survey, covering a wide range of practices related to the appropriation of mobile technologies for professional reasons. Between the two surveys, the vast majority of questions were asked in precisely the same way, while others differed slightly in wording or in response modalities¹³. In addition, the professional context of usage was explicitly specified in the wording of each question to prevent any confusion, and ensure that the responses measure the entrepreneur's professional use rather than personal use. Then, following the conceptual framework proposed by Berrou et al. (2020), we define three economic functions of mobile technologies in the business context, comprising 17 tasks that can be accomplished through eight different features at various levels of intensity.

First, the external coordination function considers mobile technologies as tools to improve market coordination with the firm's external partners, by offering new communication channels. Businesses can use mobile phones to communicate in a bilateral, or one-to-one, way with trading partners in the context of interpersonal relationships. The available

¹³This mainly involves practices for which a binary response was expected in 2017 but for which the frequency of use was collected in 2019. Therefore, the "No" modality in 2017 corresponds to the "Never" modality in 2019.

data allows us to consider three bilateral coordination tasks: coordination upstream of production with suppliers, downstream of production with customers, and coordination in a more horizontal way with colleagues or competitors in the sector. These technologies also allow for more extensive market coordination through multilateral, or one-to-many, coordination. We measure five multilateral coordination tasks: information retrieval, information storage, online sales, online advertising, and group or mass communication through social media. Second, the financial function considers digital technologies as tools for financial inclusion, allowing people to benefit from financial services other than through banking. We consider this function through the lens of mobile money use for business purposes, which allows firms to carry out cashless financial transactions. The data allows us to differentiate six different financial tasks: receiving or sending money, internationally or nationally, paying bills, and saving money for business purposes. Third, the internal coordination function considers mobile technologies as a tool for managing the firm's internal operations. It integrates the use of these technologies for internal coordination, which consists of communication with the firm's workers, and for business management practices comprising information or data storage and management of accounts, transactions, or stocks.

In total, we identified 17 tasks performed using mobile technologies, which are summarized in Table 5. We also identify several features of mobile phones through which entrepreneurs may implement these tasks. If multilateral coordination and financial tasks are all carried out through the internet or mobile money services, respectively, external and internal bilateral coordination tasks may mobilize different communication channels offered by mobile phones. The data allows us to distinguish regular cell phone calls from Voice over Internet Protocol (VoIP) calls and video calls. Similarly, we observe whether the firms use written communication channels such as SMS, IP messaging using mobile apps, or email. We therefore observe the range of effective mobile phone use for business purposes through these eight different features (Table 5). These features can be used at different levels of intensity, which we collect through the frequency of these practices on

a scale ranging from daily to weekly, less frequent, and never¹⁴. We consider a practice to be frequent if it is performed daily.

We follow the aggregation method used by McKenzie and Woodruff (2017) for business practices, which simply consists of computing the proportion of practices used by a firm, to define our measures of mobile professional usage. As we aim to consider the multidimensionality of mobile technologies appropriation by entrepreneurs, we construct three scores, each relating to specific dimensions of technology appropriation. First, we measure the number of tasks for which a firm uses mobile technologies through the *tasks score*, which is the proportion of the 17 tasks used. Second, we compute the *features score*, which is the proportion of the eight mobile phone features used by a firm. Third, we measure the intensity of such uses through the *intensity score*, which is the proportion of these features used daily by the firm. To observe the association of each economic function of mobile technologies with outcomes, we also compute sub-function scores for bilateral coordination, multilateral coordination, financial, and internal management functions. Conversely, we calculate the proportion of the 32 practices used, the *mobile total score*, which relates the total level of mobile technologies appropriation for professional purposes by a firm.

This aggregation method has some drawbacks, which we address by proposing other measures for robustness purposes. First, while we only consider practices that apply broadly across various sectors and types of activities, some might apply only to firms with specific characteristics. Especially, half of the firms are self-employed workers and therefore cannot be concerned with internal coordination with workers. In addition to the digital skills and literacy required to adopt some of these practices, we also recognize that material access partly determines the variety of tasks and features that businesses can implement, as some only require access to a GSM mobile phone, while others, such as VoIP calls, IP messaging or video calls, are only accessible through feature phones and smartphones. To test the robustness of our measures, we then compute the different scores as the proportion of practices each firm can adopt regarding their material access

¹⁴The use frequency of email has not been collected at baseline due to the low proportion of entrepreneurs having an email address. We therefore have the intensity of use of seven features.

or structural characteristics. Second, because of its additive nature, our aggregation method assigns similar weights to all indicators in the construction of our measures. To avoid this limitation, we consider the first principal component generated by multiple correspondence analysis (MCA) for each score as another measure¹⁵.

3.2 Mobile technologies usage and firm economic performance

We aim to investigate whether the use of digital technologies for business purposes has some predictive power in explaining differences in performance across informal firms while we consider it in a multidimensional way. We do not pretend to identify a causal relationship, rather, we are interested in the association between the use of mobile technologies and firm performance. Using the two-year panel data from informal businesses in the Dakar region, we estimate a standard Cobb-Douglas production function:

$$Y_{i,t} = \beta_0 + \beta_1' K_{i,t} + \beta_2' L_{i,t} + \beta_3 DT_{i,t} + \sum_k \beta_k X_{i,t} + \mu_i + \epsilon_{i,t}, \quad (1)$$

where Y_{it} is log sales or log value-added¹⁶ for firm i in year t . K_{it} stands for physical capital of the firm, and L_{it} for labor inputs. For capital, we control for the log of physical capital and the log of the value of inventories. To deal with null values of capital or stock, we follow Battese (1997) and include dummy variables for having zero physical capital and zero inventory of value. For labor inputs, we control for the log of total workers' monetary and non-monetary remuneration, again including a dummy variable indicating null values. X_{it} is a vector of k time-varying control variables including the firm's and entrepreneur's characteristics such as registration and payment of taxes status, access to electricity, ownership of a bank account, whether the activity takes place at the entrepreneur's home, and the departmental location in the Dakar region. We also include a year dummy variable to control for time-fixed effects and an interaction term between

¹⁵We consider only the first dimension as it represents more than 80% of the total inertia for every score.

¹⁶To deal with negative values, we add the minimum plus one to each value-added values.

time-fixed effects and department dummies. This interaction term is used to control for the possibility of uneven economic development between the four departments over time and for department-specific exogenous shocks¹⁷.

Since entrepreneurs decide whether and how they use their mobile phones for business purposes, correlation with the error term is likely to occur due to unobserved characteristics, leading to biased estimates of the coefficient of interest. For instance, the usage level of mobile technologies may differ according to the entrepreneur's human capital and technology familiarity, as well as the specificity of the firm's activity. In order to address this omitted variable bias, we estimate this panel data model using a fixed effects (FE) estimator, to capture the unobserved heterogeneity of firms and entrepreneurs, which is likely to be time-invariant, especially in a two-year panel. However, we acknowledge that there may be a simultaneity bias, as the use of mobile technologies can lead to better performance, while, at the same time, the most successful firms are more motivated and capable of using these technologies extensively. Thus, our empirical strategy aims not to identify a causal relationship between professional usage of mobile technologies and firms' economic performance, but to demonstrate how different dimensions of mobile technologies appropriation allow us to predict performance differences across small informal firms.

The coefficient of interest β_3 estimates the association between mobile technologies usage and the firm's economic outcomes. As mentioned above, we use two outcome variables (log sales and log value-added) and run the model separately for each. By considering these outcome variables, we want to investigate whether these new business practices are associated differently with economic performance, depending on whether we consider their extensive or intensive margins. We consider that the extensive margin is the firm's total sales, as it captures the firm's ability to sell its production and multiply transactions. We consider that the intensive margin is the firm's value-added, as it captures the efficiency of the firm's production process. The survey implemented a disaggregated measure of economic performance, considering the seasonal variability of sales, and an

¹⁷For example, some entrepreneurs stated that their business, located near certain train stations, was disrupted by the work on the Train Express Regional in the department of Pikine.

accurate measure of raw material and commodity costs as well as current expenses. The financial performances reported by entrepreneurs are expressed in local currency. Price differences over time are adjusted via the use of price deflators.

The variable of interest DT_{it} takes different forms. We estimate separate regression for our overall measure of mobile technologies professional usage (the *mobile total score*) and for each sub-component (the *features score*, the *intensity score*, and the *tasks score*). Finally, we run the model with all sub-functions scores to observe the association between firms' economic outcomes and specific economic functions of mobile technologies.

3.3 Identifying potential pathways

Further, we test a series of potential channels through which professional usage of mobile technologies may affect the informal firms' economic performance. Specifically, we identify different intermediate outcomes at the firm-level that may be affected by the overall usage of mobile technologies or by specific functions.

First, we test whether the use of mobile technologies is associated with a lower level of informality. By reducing information search costs, entrepreneurs who use mobile technologies, and particularly the internet, can have better access to information on the legal framework and the registration procedure to follow. In addition, informal businesses can benefit from greater financial inclusion by adopting digital financial services such as mobile money. Ngumkeu and Okou (2021) argues that this digitalization process of economic transactions could allow informal businesses to join the formal transaction realm and thus induce their formalization. To test these assumptions, we consider two intermediate outcomes: the firm's registration¹⁸ and formal tax payment status.

Second, the usage of mobile technologies may help to overcome financial constraints and empower entrepreneurs in their capital accumulation process. Mobile technologies can improve financial inclusion and enhance credit access, principally by lowering transaction costs. Indeed, data from mobile money transactions can reduce information asymmetry

¹⁸Whether the firm has a NINEA.

between informal businesses and financial institutions (Nguimkeu and Okou, 2021), while more frequent communication with suppliers can enhance trust and access to relational contracts such as supplier credit (Rudder, 2020). In addition, one barrier to capital accumulation may be limited access to formal savings or a safe place to save (Batista and Vicente, 2020). Indeed, entrepreneurs, especially women, may face important intra-household sharing pressure or forced solidarity from relatives (Riley, 2022; Baland et al., 2011), hindering the reinvestment of profits in the business (Grimm et al., 2017). Thus, entrepreneurs can use their mobile money accounts to save money, reduce sharing pressure, and then increase their investment capacity. Finally, mobile technologies usage can enhance market coordination and overall access to information. It may reduce uncertainties and better investment decisions, notably due to better access to real-time demand characteristics (Becchetti et al., 2003). We consider two intermediate outcomes to test the credit access channel: access to bank credit and whether the entrepreneur reports being able to borrow one million XOF from any source to invest in the business. Then, we consider different investment behaviors: replacement investment and net capital accumulation. In the latter, we distinguish intensive capital accumulation, which increases the productive capacity of the business, from extensive capital accumulation, which relates to the entrepreneur's diversification behavior, which reinvests in another economic activity.

Third, we test whether professional usage of mobile technologies is associated with informal firms' innovation capacity (Cirera et al., 2016). Digital technologies can be considered as innovation inputs, as they may integrate the firm's innovation process. Indeed, by improving firms' access to knowledge (Paunov and Rollo, 2016), notably through the use of the internet, digital technologies provide opportunities to learn new practices and production techniques, acquire new skills, or find inspiration and advice. Moreover, these new technologies may enhance firms' innovation performance through improved communication and market coordination with trading partners. Better knowledge about customer preferences may help firms identify market opportunities for new products and services or expected improvement of existing production through

customer feedback. Similarly, better coordination with suppliers can support firms' innovation through better access to information about new products or processes. Finally, horizontal coordination with the sector's competitors or colleagues can enhance knowledge diffusion about new products or production techniques. However, competition among similar firms must be a barrier to knowledge diffusion (Fafchamps and Quinn, 2018). To explore this potential pathway, we consider technological and non-technological innovation outcomes through product, process, and marketing innovations in the year prior to the second survey wave (Charmes et al., 2018). Product innovation indicates whether the firm has significantly improved a previously sold good or service, or started to offer a new one. Process innovation indicates whether the firm has introduced any new, or significantly improved, production process. Marketing innovation indicates whether the firm has introduced any new or significantly improved ways of selling goods or services¹⁹.

Then, we test whether professional usage of mobile technologies is associated with these intermediate outcomes, which all are dummy variables. For the ones for which we have data for both survey waves²⁰, we use linear probability models (LPM) rather than nonlinear models for binary outcomes²¹. It is a common approach in panel data econometrics (Beuermann et al., 2012; Rajkhowa and Qaim, 2022) that allows us to exploit the panel nature of our dataset and address unobserved endogeneity through fixed effects. In contrast, using a nonlinear fixed-effects model would result in biased estimates, as stated in Greene (2004). As we do not have information on innovation outcomes for both survey waves, we use cross-sectional probit models to estimate the association between baseline professional usage of mobile technologies and innovation outcomes measured during the last wave. Therefore, we add the time-invariant characteristics of the entrepreneur and the firm to the controls in equation (1).

¹⁹For example, marketing innovation includes new packaging, implementation of advertising or promotion, or new sales channels.

²⁰Intermediate outcomes linked to firm's level of informality, credit access, and capital accumulation.

²¹Thus, we use the same model described in equation (1) with Y_{it} being successively the different intermediate outcomes.

4. Results

4.1 Overall trends in mobile technologies usage between 2017 and 2019

The adoption of digital practices by informal activities in the Dakar region has made significant progress between 2017 and 2019 (Table 5). Material access inequalities within the informal sector of Dakar are narrowing as entrepreneurs increasingly invest in mobile phones. While the rate of mobile phone ownership had already reached saturation in 2017, access to smartphones continued to expand over the period. Indeed, 79% of the entrepreneurs surveyed stated that they had acquired at least one mobile phone in the last two years, and the vast majority consider that they have acquired a more advanced model.

The perceived utility of mobile phones for business purposes has increased, with the proportion of entrepreneurs who consider its use as indispensable increasing from 36% to 64% over the period. In line with this increasing perceived usefulness, the use of the different communication features accessible through mobile phones and smartphones also showed a positive trend, with most of them being used by more entrepreneurs and more intensively. This is particularly the case for voice calls, where the proportion of daily users has increased significantly for cell and VoIP calls. For the latter, the adoption rate also increased, in line with the proliferation of smartphones. In contrast, we do not observe any significant diffusion or intensification of written communication uses such as SMS and IP messaging, while the use of e-mail remains anecdotal. One reason may be the limited educational attainment of entrepreneurs and their trading partners, the ability to read and write of both interlocutors being indispensable for these types of usage. It highlights the pervasive dominance of oral communication in the business interactions of informal entrepreneurs, confirmed by the emergence of new uses of mobile technologies such as voice messages, already adopted by more entrepreneurs than text messages.

Table 5: Evolution of professional mobile technologies usage (2017-2019)

	2017	2019	t-Test
<i>Device ownership</i>			
Mobile phone	0.98	0.98	1.00
Smartphone	0.65	0.77	0.00***
<i>Mobile technologies features</i>			
Cell calls	0.95	0.97	0.29
VoIP calls	0.42	0.64	0.00***
Video calls	0.38	0.34	0.31
SMS	0.35	0.38	0.40
IP messaging	0.34	0.38	0.35
Mail	0.05	0.08	0.14
Mobile money	0.60	0.75	0.00***
Internet	0.65	0.68	0.39
<i>Usage intensity of features</i>			
Cell calls - Daily	0.47	0.62	0.00***
VoIP calls - Daily	0.15	0.40	0.00***
Video calls - Daily	0.08	0.07	0.64
SMS - Daily	0.07	0.07	1.00
IP messaging - Daily	0.13	0.14	0.55
Mobile money - Daily	0.01	0.08	0.00***
Internet - Daily	0.21	0.28	0.06*
<i>Tasks implemented</i>			
Bilateral coordination - Customers	0.89	0.94	0.03**
Bilateral coordination - Suppliers	0.71	0.80	0.01**
Bilateral coordination - Competitors	0.50	0.64	0.00***
Internet - Get information	0.56	0.47	0.03**
Internet - Sell	0.24	0.18	0.07*
Internet - Advertise	0.31	0.32	0.66
Internet - Store document online	0.13	0.04	0.00***
Internet - Facebook	0.21	0.29	0.03**
Mobile Money - Receive	0.52	0.72	0.00***
Mobile Money - Send	0.58	0.64	0.10*
Mobile Money - National transfers	0.58	0.66	0.04**
Mobile Money - International transfers	0.16	0.18	0.52
Mobile Money - Save	0.26	0.43	0.00***
Mobile Money - Bills payment	0.37	0.43	0.08*
Internal management - Coordination with workers ^a	0.77	0.89	0.00***
Internal management - Accounts, transactions, or stocks	0.06	0.06	0.87
Internal management - Information or data storage	0.17	0.16	0.83
Number of observations	304	304	

Notes: ^a Proportion reported for firms that employ at least one worker. *p < 0.05, **p < 0.01, ***p < 0.001.

Source: Author's computations.

The diffusion of communication features aligns with the importance of bilateral coordination usage among informal entrepreneurs in Dakar. Almost all entrepreneurs acknowledge that they use mobile technologies to communicate with at least one type of business partner, coordination with customers being the most common, followed by coordination with suppliers. All types of bilateral coordination usage increase between the two survey waves, providing further evidence of the ongoing digitalization of business interactions. Similarly, the use of mobile money for business purposes is widespread among the surveyed entrepreneurs. In 2019, three-quarters of entrepreneurs report using mobile money, with receiving and sending money via mobile money services increasing over the period. However, money transfers remain nationally embedded, with international transfers involving only a few entrepreneurs. In addition, more entrepreneurs are now using mobile money accounts for savings purposes. Then, in line with bilateral coordination, entrepreneurs are increasingly involved in using the financial functions of mobile technologies, although daily or weekly users remain scarce.

At the same time, we observe a contrasting trend in internet use for multilateral purposes. On the one hand, the rate of internet use and the frequency of such use show a slight increase. On the other, the different tasks associated with multilateral coordination are less or equally adopted in 2019 than two years before. It remains unclear how much it reflects the real evolution of such practices over time, as slightly different ways of asking questions were implemented between the two surveys to measure the frequency of internet use. Nevertheless, the more precise wording of the question in the last round of the survey implies that this contrasted evolution may be due to an upward bias in the baseline survey. Finally, mobile phones are an important internal coordination tool, with almost all employers using them to communicate with employees (89%), showing a slight increase from 2017. However, the adoption of other digital internal management practices remains low.

Table 6 shows that our aggregated scores capture these different trends. In 2017, on average, surveyed firms employed 36% of the 32 mobile phone practices measured. The average rises to 42% in 2019, illustrating the global trend of mobile professional usage

Table 6: Evolution of mobile technologies professional usage scores (2017-2019)

Score	2017		2019		t-Test
	Mean	sd.	Mean	sd.	
Mobile total score	0.36	0.22	0.41	0.21	0.00***
Features score	0.47	0.29	0.53	0.27	0.01***
Intensity score	0.16	0.20	0.22	0.22	0.00***
Tasks score	0.40	0.24	0.44	0.22	0.03**
Function score - Bilateral coordination	0.70	0.30	0.79	0.26	0.00***
Function score - Multilateral coordination	0.29	0.32	0.26	0.30	0.24
Function score - Financial	0.41	0.37	0.51	0.33	0.00***
Function score - Internal management	0.25	0.25	0.24	0.25	0.71

Notes: The *mobile total score* is the proportion of 32 practices that are used by the firm. The *features score*, *intensity score*, and *tasks score* are subcomponents score for proportion of features, daily features, and tasks that are used by the firm, respectively. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

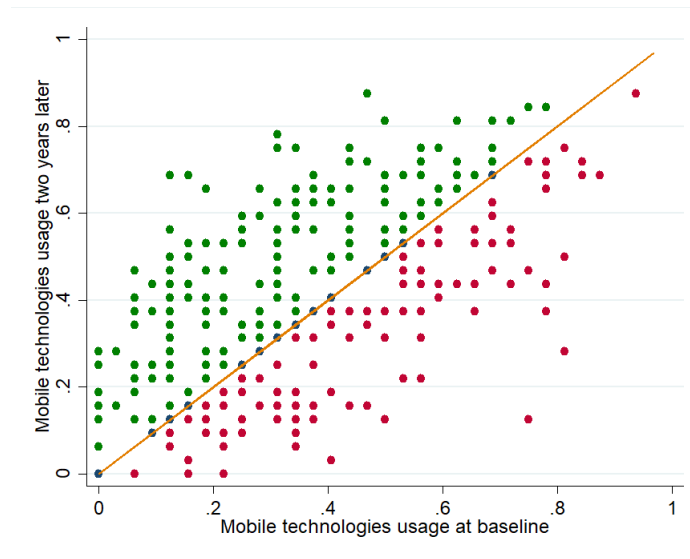
Source: Author's computations.

diffusion over the period. We make similar observations for the average number of tasks implemented, the range of features, and the intensity of feature uses. Nevertheless, these observations hide significant disparities, as mentioned above. Indeed, the global increase of such practices reflects mainly positive diffusion trends in bilateral coordination and mobile money usage. The two other sub-functions, multilateral coordination through the use of the internet and internal management, display a lower or equal average than in the baseline.

Then, we examine how stable these mobile professional uses are over a two-year period at the individual level by plotting the *mobile total score* obtained by the firms in 2019 against that in the baseline (Figure 3). The Pearson correlation is 0.597 and confirms the positive correlation between the firm's usage between the two survey waves²². Descriptive statistics show that 59% of surveyed firms employ a higher proportion of the 32 mobile technologies practices measured in 2019 compared to 2017, confirming the positive global trend observed. While few entrepreneurs obtain precisely the same score, more than one tier appears to have lower mobile professional usage than in the baseline.

This evolution in overall mobile technologies usage may be put in perspective with the level of mobile technologies appropriation at baseline. For this purpose, we identify three

²²By comparison, McKenzie and Woodruff (2017) find a Pearson correlation coefficient of 0.591 between business practices in a one-year follow-up survey using data from Ghana, Kenya, Nigeria, and Sri Lanka.

Figure 3: Evolution of the *mobile total score* over time (2017-2019)

Notes: Data points on the 45° line are firms using the same proportion of the 32 practices in 2019 as in 2017. Green data points are those using a higher proportion, and red points are those using a lower proportion of digital practices.

Source: Author's computations.

levels of appropriation: basic, intermediate, and advanced users²³. Over the period, more than 30% of firms are involved in upward mobility, while 19% are involved in downward mobility. Interestingly, the positive global trend in mobile technologies professional usage is driven by the firms with low usage at baseline (Table 7). More than 80% of basic users obtained a higher *mobile total score* in 2019, resulting in 61% of upward mobility, almost exclusively toward intermediate user profile. Similarly, most intermediate users (59%) obtained a higher *mobile total score* in 2019, conducting to 28% of upward mobility. In contrast, advanced users at baseline are 65% to obtain a lower *mobile total score* in 2019, leading to downward mobility for 44% of them, almost exclusively toward intermediate user profile.

4.2 Evolution of mobile technologies usage and firm dynamics

In this section, we aim to assess whether levels of mobile technologies appropriation at baseline, and their subsequent evolution, are significantly associated with firm dynamics.

²³We use the first and third quartiles of the *mobile total score* distribution at baseline as thresholds. Basic users use less than 19% of the 32 digital practices, and advanced users implement at least 56% of these practices.

Table 7: Transition matrix across usage levels (2017-2019) (%)

Usage level in 2019	Usage level in 2017			Total
	Basic user	Intermediate user	Advanced user	
Basic user	38.8	17.6	1.4	19.7
Intermediate user	55.3	54	42.3	51.7
Advanced user	5.9	28.4	56.3	28.6
Total	28	48.7	23.3	100

Notes: Column percentages are reported.

Source: Author's computations.

For this purpose, we first examine whether professional usage of mobile technologies at baseline predicts firms' survival in the period between baseline and follow-up surveys, by estimating binomial regressions. We consider the upper bound of the mortality rate (27.4%), including the observed business closures and all firms that could not be found by telephone or in the field. Table 8 shows that overall appropriation of mobile technologies at baseline is not significantly associated with firms' survival (column 1)²⁴. However, we find that the proportion of tasks used at baseline is positively associated with a two-year firm's survival, although this association is not significant at the 10% level (column 2). Congruent with this finding, column 3 shows that this association is driven by bilateral coordination usage, suggesting that better market coordination is significantly associated with informal firms' survival. Indeed, using the three tasks of bilateral coordination is associated with a 19% points higher likelihood of survival.

Second, we estimate the association between professional usage of mobile technologies and sales growth patterns using linear regressions (Table 9). We measure sales growth as the change in the logarithm of sales between the two survey waves (McKenzie and Woodruff, 2017; Léon, 2022). Column 1 shows that initial mobile technologies usage is not significantly associated with subsequent sales growths²⁵. However, we find in column 2 that improvement in the *mobile total score* over the period is associated with about 56% higher growth in sales compared to firms with decreasing overall score, even after controlling for initial usage level. Similarly, compared to firms with a lower level of appropriation in 2019 than at baseline, column 3 shows that firms that keep the same level

²⁴We find similar results for regression estimates with levels of appropriation as explanatory variables.

²⁵We find similar results for regression estimates with subcomponents scores as explanatory variables.

of appropriation over the period and those that reach a higher level of appropriation have significantly higher sales growth. Hence, the mobile technologies appropriation level at baseline does not help predict subsequent sales growth in a two-year period, although technology adoption dynamics appear to be significantly associated with sales growth patterns.

Table 8: Association of baseline mobile technologies usage with two-year survival

	Two-year survival		
	(1)	(2)	(3)
Mobile total score	0.020 (0.125)		
Features score		-0.185 (0.130)	-0.177 (0.130)
Intensity score		-0.014 (0.116)	-0.019 (0.116)
Tasks score		0.216 (0.142)	
Function score - Bilateral coordination			0.192** (0.078)
Function score - Multilateral coordination			-0.002 (0.093)
Function score - Financial			0.005 (0.071)
Function score - Internal management			0.090 (0.115)
Smartphone	0.073 (0.048)	0.104** (0.052)	0.097* (0.053)
Controls for firm and entrepreneur	Yes	Yes	Yes
Controls for baseline firm's performance	Yes	Yes	Yes
Observations	500	500	500

Notes: Average marginal effects from probit estimation for two-year survival. Robust standard errors are in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Source: Author's computations.

4.3 Association of mobile technologies usage with economic performance

Table 10 reports the estimation results of equation (1) with the logarithm of sales as dependent variables. We find a positive and significant association between the digitalization of business operations and monthly sales (column 1). After controlling for capital and labor inputs, time-variant firm characteristics, and smartphone ownership, a one-standard-deviation (0.22) increase in the *mobile total score* is associated with 0.15 log points (16%) higher sales. In other words, adopting all of the 32 mobile professional

practices is associated with a 95% increase in sales compared to mobile technologies non-users.

To further understand this significant association, columns 2, 3, and 4 present the regression results for each sub-component of the overall score. Column 2 shows that the number of mobile phone features used is not significantly associated with sales, demonstrating that mobile phone use without any notion of intensity or economic functions is not correlated with economic performance. However, column 3 suggests that daily use of these features, namely phone calls, text messages, internet, and mobile money, is significantly associated with higher sales. Indeed, a one-standard-deviation (0.19) increase in *intensity score* is associated with a 12% increase in sales. Finally, column 4 shows a significant positive association between the number of tasks handled through mobile phones and the firm's monthly sales. We find that a one-standard-deviation (0.40) increase in *tasks score* is associated with 21% higher sales. These results highlight that the association between informal firms' sales and their professional use of mobile technologies is driven primarily by the intensity of their use and the number of economic purposes for which they mobilize these technologies. Controlling for each dimension of

Table 9: Association of baseline mobile technologies usage with two-year sales growth

	Sales growth		
	(1)	(2)	(3)
Mobile total score	-0.114 (0.375)	0.660 (0.402)	0.637 (0.416)
Lower score (Ref.)		-	
Same score		0.140 (0.164)	
Higher score		0.562*** (0.120)	
Decrease appropriation level (Ref.)			-
Same appropriation level			0.443*** (0.137)
Increase appropriation level			0.722*** (0.169)
Smartphone	-0.011 (0.153)	-0.035 (0.153)	-0.077 (0.150)
Baseline log(Sales)	-0.487*** (0.062)	-0.480*** (0.061)	-0.498*** (0.061)
Controls for firm and entrepreneur characteristics	Yes	Yes	Yes
Observations	304	304	304

Notes: Estimate coefficients from linear regression estimation for two-year sales growth. Robust standard errors are in parentheses. *p < 0.05, **p < 0.01, ***p < 0.001.

Source: Author's computations.

Table 10: Association between mobile technologies usage and monthly sales (FE models)

	log(Sales)				
	(1)	(2)	(3)	(4)	(5)
log(Employee remuneration)	0.171** (0.075)	0.173** (0.075)	0.176** (0.074)	0.169** (0.074)	0.172** (0.075)
log(Physical capital assets)	0.068 (0.043)	0.071* (0.043)	0.065 (0.042)	0.071* (0.043)	0.065 (0.043)
log(Inventories)	0.030 (0.036)	0.033 (0.036)	0.034 (0.036)	0.032 (0.036)	0.033 (0.037)
Operate at home	0.446*** (0.151)	0.440*** (0.153)	0.416*** (0.154)	0.456*** (0.152)	0.431*** (0.154)
Registered (NINEA)	0.074 (0.123)	0.085 (0.120)	0.114 (0.122)	0.065 (0.123)	0.095 (0.126)
Pay formal taxes	0.153 (0.122)	0.137 (0.122)	0.152 (0.120)	0.151 (0.123)	0.163 (0.121)
Bank account	0.090 (0.097)	0.099 (0.098)	0.099 (0.098)	0.097 (0.098)	0.095 (0.097)
Electricity access	0.014 (0.156)	0.009 (0.157)	0.018 (0.153)	0.004 (0.156)	0.015 (0.154)
Mobile total score	0.669** (0.320)				
Features score		0.243 (0.258)			-0.142 (0.298)
Intensity score			0.613*** (0.210)		0.559** (0.231)
Tasks score				0.465* (0.262)	0.386 (0.281)
Smartphone	-0.068 (0.128)	-0.058 (0.138)	-0.033 (0.123)	-0.034 (0.124)	-0.023 (0.137)
Constant	9.456*** (1.035)	9.578*** (1.025)	9.616*** (1.010)	9.443*** (1.046)	9.494*** (1.038)
Firm and entrepreneur fixed effect	Yes	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes	Yes
Department fixed effect	Yes	Yes	Yes	Yes	Yes
Year x department fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	608	608	608	608	608

Notes: Coefficients of dummy variables for zero values of physical capital asset, inventory, and employee remuneration are omitted. Robust standard errors are in parentheses. *p < 0.05, **p < 0.01, ***p < 0.001.

Source: Author's computations.

mobile phone appropriation, column 5 shows that the intensity of use prevails over the number of tasks implemented.

Table A1 presents the corresponding regressions with the log value-added as dependent variable. Column 1 shows that overall mobile professional usage is again significantly

associated with firms' performance. The various sub-components also display the same association patterns as for sales. However, the coefficient of the *intensity score* is lower in magnitude for value-added than for sales (column 3). Indeed, a one-standard-deviation (0.19) increase in *intensity score* is associated with a 5% increase for value-added against 12% for sales. In addition, after controlling for each dimension of mobile technologies appropriation, the number of tasks appears to primarily drive the association between value-added and mobile professional usage (column 5). Hence, different usage patterns seem to be correlated with the level of sales and value-added, both measuring different dimensions of informal firms' economic performance²⁶.

In order to explore the different usage patterns associated with turnover and value-added, Table 11 shows the regression results for each dependent variable with the *intensity score* and the *tasks score* split into sub-functions. Column 2 shows that the association between sales and intensity of feature usage is mainly driven by the daily use of bilateral coordination features. Indeed, using voice calls, video calls, or text messages daily for business purposes is associated with a 48% increase in sales compared to firms that never use these features. The importance of the intensity of such uses is confirmed by the non-significance of the coefficient of the bilateral coordination function score in column 1. Hence, it appears that professional usage of mobile technologies probably affects informal firms' economic performance in the extensive margin, mainly through better market coordination with trading partners, as it may increase the firm's ability to sell its output of goods or services and to multiply economic transactions. In contrast, columns 3 and 4 show that firms' value-added is closely associated with mobile money usage. Although daily use of mobile money services does not appear to be significantly associated with value-added (column 4), the financial function of the mobile technologies captured by such use is the only one that is significantly associated with value-added in column 3. Hence, each dimension of economic performance seems to be associated with specific functions of mobile technologies, although these disaggregated results probably hide

²⁶We run the same regressions for firms' net profit and find no significant association with our different measures of mobile technologies usage. However, findings suggest that the intensity of use and mobile money may positively affect firms' net profit, but the coefficients are not significant at the 10% confidence level.

Table 11: Association between intensity of use, specific functions and economic performance (FE models)

	log(Sales)		log(Value-added)	
	(1)	(2)	(3)	(4)
Function score - Bilateral coordination	0.220 (0.163)		0.005 (0.124)	
Function score - Multilateral coordination	0.070 (0.173)		0.256 (0.270)	
Function score - Financial	0.098 (0.139)		0.190** (0.083)	
Function score - Internal management	0.146 (0.176)		-0.053 (0.214)	
Bilateral coordination intensity - Never (Ref.)		-		-
Less than weekly		0.181 (0.214)		0.004 (0.097)
Weekly		0.297 (0.208)		0.016 (0.107)
Daily		0.480** (0.208)		0.110 (0.111)
Mobile money intensity - Never (Ref.)		-		-
Less than weekly		0.029 (0.105)		0.025 (0.098)
Weekly		0.019 (0.146)		0.221 (0.149)
Daily		0.073 (0.217)		0.173 (0.119)
Internet connection intensity - Never (Ref.)		-		-
Less than weekly		-0.220 (0.138)		-0.003 (0.102)
Weekly		-0.146 (0.133)		0.099 (0.097)
Daily		-0.026 (0.150)		0.158 (0.179)
Smartphone	-0.043 (0.126)	0.030 (0.134)	-0.063 (0.081)	-0.065 (0.086)
Control for inputs factors	Yes	Yes	Yes	Yes
Control for time-variant firm's characteristics	Yes	Yes	Yes	Yes
Firm and entrepreneur fixed effect	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes
Department fixed effect	Yes	Yes	Yes	Yes
Year x department fixed effects	Yes	Yes	Yes	Yes
Observations	608	608	608	608

Notes: Robust standard errors are in parentheses. *p < 0.05, **p < 0.01, ***p < 0.001.

Source: Author's computations.

complementary and cumulative effects between features and tasks that are captured in the overall association of each score in Tables A1 and 10.

We provide robustness checks in Tables A2 and A3, where we use alternative methods in aggregating mobile professional usage. First, while we compute the different scores as the proportion of practices that each firm has the potential to adopt regarding their material access or structural characteristics, we find similar results except for the association

between value-added and the *score intensity*, which becomes insignificant at the 10% level (Table A3, column 2). Second, we find similar results in magnitude and statistical significance while considering the individual first-factor coordinates for each score, confirming the robustness of our results.

4.4 Potential channels of the association between mobile technologies usage and business outcomes

Next, in order to identify the potential channels through which professional usage of mobile technologies may affect small firms' economic performance, we estimate separate models for different intermediate outcomes²⁷. First, we explore whether using mobile technologies is associated with lower informality levels through a higher probability of being registered or paying formal taxes. Table 12 reports the regression results of fixed-effects linear probability models (FE-LPM) for these two intermediate outcomes. We do not find any significant association between these formality criteria and overall mobile professional usage (columns 1 and 4) or sub-components scores (columns 2 and 5). However, specific economic functions are associated with registration or paying formal taxes. On the one hand, mobile money usage is positively and significantly associated with registration status (column 3). Firms that use all of the six financial functions of mobile money are 13% points more likely to be registered. It confirms that mobile money may allow informal businesses to join the formal transaction realm and engage in transactions with more formal partners, which probably leads to their partial formalization. Conversely, the usage of mobile technologies for internal management purposes is negatively and significantly associated with the payment of formal taxes. We find that a one-unit deviation in the internal management score decreases the probability of paying formal taxes by 20% points (column 6). Better internal management appears to benefit informal enterprises by allowing them to avoid formal taxes. There is no clear evidence to explain this result, but we argue that it is potentially due to a greater ability to dissimulate or misreport their level of activity to local authorities.

²⁷Table A4 presents some descriptive statistics on these intermediate outcomes.

Table 12: Association between mobile technologies usage and formality (FE-LPM)

	Registered (NINEA)			Pay formal taxes		
	(1)	(2)	(3)	(4)	(5)	(6)
Mobile total score	0.088 (0.133)			-0.152 (0.118)		
Features score		-0.018 (0.122)			0.089 (0.136)	
Intensity score		-0.144 (0.111)			-0.081 (0.119)	
Tasks score		0.196 (0.141)			-0.175 (0.151)	
Function score - Bilateral coordination			-0.005 (0.053)			-0.031 (0.064)
Function score - Multilateral coordination			0.036 (0.077)			-0.107 (0.080)
Function score - Financial			0.126*** (0.046)			0.055 (0.059)
Function score - Internal management			-0.139 (0.096)			-0.200* (0.110)
Smartphone	-0.007 (0.037)	-0.000 (0.040)	0.011 (0.039)	-0.038 (0.052)	-0.057 (0.055)	-0.017 (0.053)
Inputs factors	Yes	Yes	Yes	Yes	Yes	Yes
Time-variant firm's characteristics	Yes	Yes	Yes	Yes	Yes	Yes
Firm and entrepreneur fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Department fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Year x department fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	608	608	608	608	608	608

Notes: Robust standard errors are in parentheses. *p < 0.05, **p < 0.01, ***p < 0.001.

Source: Author's computations.

We also seek to identify whether mobile technologies usage may be associated with better economic performance through increased access to credit (Table A5). We find no evidence that access to bank credit is associated with the range and intensity of mobile technologies usage. For instance, only bank account ownership is associated with access to formal credit after controlling for time-variant and time-invariant firm characteristics. It relates to the limited access to these financial services, with only 12% of firms having access in 2019. In addition, professional usage of mobile technologies is not associated with the perception of being able to access one million XOF through external funding sources. Hence, higher appropriation of mobile technologies does not seem to be associated with lower credit constraints in the informal sector in Dakar.

Mobile technologies may also enhance the economic performance of informal firms through higher capital accumulation potential. Tables A6 and 13 report the regression

Table 13: Association between mobile technologies usage and capital accumulation (FE-LPM)

	Replacement investment			Intensive accumulation		
	(1)	(2)	(3)	(4)	(5)	(6)
Mobile total score	0.221 (0.190)			0.549*** (0.205)		
Features score		0.030 (0.167)			-0.169 (0.208)	
Intensity score		0.329** (0.166)			0.302* (0.176)	
Tasks score		-0.048 (0.203)			0.475** (0.209)	
Function score - Bilateral coordination			-0.057 (0.102)			0.054 (0.101)
Function score - Multilateral coordination			-0.016 (0.114)			0.028 (0.123)
Function score - Financial			0.010 (0.095)			0.211** (0.095)
Function score - Internal management			0.239* (0.140)			0.149 (0.138)
Smartphone	-0.080 (0.078)	-0.078 (0.078)	-0.071 (0.077)	-0.064 (0.078)	-0.018 (0.083)	-0.026 (0.081)
Inputs factors	Yes	Yes	Yes	Yes	Yes	Yes
Time-variant firm's characteristics	Yes	Yes	Yes	Yes	Yes	Yes
Firm and entrepreneur fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Department fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Year x department fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	608	608	608	608	608	608

Notes: Robust standard errors are in parentheses. *p < 0.05, **p < 0.01, ***p < 0.001.

Source: Author's computations.

results for three investment behaviors: replacement investment, intensive capital accumulation, and extensive capital accumulation. First, we find that intensive capital accumulation is positively and significantly associated with the overall appropriation of mobile technologies. Column 4 shows that a one-standard-deviation (0.22) increase in the *mobile total score* is associated with a 12% points higher probability that firms have invested to expand their physical capital stock in the year prior to the survey. This association stands out also with the intensity of feature usage and the number of tasks implemented (column 5). In column 6, mobile money adoption appears to drive the association between mobile technologies usage and intensive capital accumulation. Next, no significant associations are found between the *mobile total score* and the other investment behaviors (columns 1 in Table 13 and column 1 in Table A6). However, the

intensity score is positively and significantly associated with the probability that the firm has invested to maintain the output capacity that is lost through capital deterioration or scrapping (column 2). Similarly, column 3 shows that mobile technologies usage for internal management purposes is positively associated with this form of investment. In contrast, firms with entrepreneurs using mobile technologies for internal management are less likely to adopt diversification strategies by investing in another economic activity (column 3 in Table A6). Then, although we find that professional uses of mobile technologies do not seem to overcome the credit constraints faced by informal entrepreneurs, it appears that these new technologies help them reinvest their profits, probably by improving the management of their finance and savings capacity. It is supported by the high proportion of firms that report using their own funds to make these investments²⁸.

Finally, we investigate to which extent professional usage of mobile technologies at the baseline predicts subsequent firms' innovation behaviors. Table 14 reports the average marginal effects from the cross-sectional probit models for product, process, and marketing innovation. Column 1 shows that baseline *mobile total score* positively and significantly predicts the introduction of any new or improved goods or services in the last year before the second survey wave. A one-unit deviation in the baseline score increases the probability of implementing product innovation by 43% points. We do not observe such a significant association for the other forms of innovation, either for the overall score or its sub-components. However, specific economic functions of mobile technologies appear to be significantly associated with firms' innovation behaviors. Multilateral coordination, through the use of the internet at baseline, predicts significantly subsequent product and process innovation. Columns 3 and 6 show that a one-unit deviation in the proportion of tasks attached to multilateral coordination increases the probability of implementing new or improved products and processes by 27% and 23% points, respectively. Hence, internet usage is significantly associated with firms' technological

²⁸About 90% of firms concerned by these investment behaviors declare this source of financing in both survey waves.

innovation capacity. In contrast, we find no significant association between baseline professional usage of mobile technologies and marketing innovation (Table A7).

Table 14: Association between baseline mobile technologies usage and innovation behaviors in 2019 (Probit models)

	Product innovation			Process innovation		
	(1)	(2)	(3)	(4)	(5)	(6)
Mobile total score	0.428*** (0.153)			0.200 (0.155)		
Features score		0.234 (0.193)			0.056 (0.177)	
Intensity score		0.070 (0.159)			-0.162 (0.156)	
Tasks score		0.117 (0.199)			0.228 (0.184)	
Function score - Bilateral coordination			-0.093 (0.108)			-0.162 (0.102)
Function score - Multilateral coordination			0.268** (0.114)			0.226** (0.100)
Function score - Financial			0.121 (0.085)			0.048 (0.083)
Function score - Internal management			-0.064 (0.146)			0.057 (0.135)
Smartphone	-0.066 (0.065)	-0.087 (0.071)	-0.037 (0.067)	0.029 (0.067)	0.034 (0.072)	0.028 (0.067)
Inputs factors	Yes	Yes	Yes	Yes	Yes	Yes
Firm's and entrepreneurs characteristics	Yes	Yes	Yes	Yes	Yes	Yes
Department fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Observations	608	608	608	608	608	608

Notes: Average marginal effects from probit estimation. Robust standard errors are in parentheses. *p < 0.05, **p < 0.01, ***p < 0.001.

Source: Author's computations.

5. Conclusion

Most firms in sub-Saharan Africa are micro or small enterprises with low productivity levels, facing important internal and external constraints. These firms, which are mostly informal, are not excluded from the digital revolution, as they largely embrace a process of digitalization of their business operations (Esselaar et al., 2006; Atiyas and Dutz, 2023). While infrastructural and material access to these new technologies is now almost universal, their appropriation by informal entrepreneurs is bound to be uneven. We argue that these digital inequalities, expressed by effective uses of varying degrees of diversity

and intensity, might explain some of the performance heterogeneity of small firms, in addition to traditional factors such as motivation or entrepreneurial skills (McKenzie and Woodruff, 2017). Indeed, using these general-purpose technologies can benefit small firms in many ways that lead to productivity gains (Berrou et al., 2020).

Using panel data on informal firms from the Dakar region of Senegal, we compute a measure that takes into account three dimensions of their appropriation of mobile technologies: the number of tasks, the range of features, and the intensity of usage. Our results confirm that advanced appropriation of these technologies is correlated with better economic performance in the informal sector of Dakar. First, the firms' dynamics are closely tied to their mobile technologies usage and subsequent evolution over the period, both in terms of survival and sales growth. Second, higher appropriation levels are significantly associated with higher sales and value-added, confirming the positive effects of digital technologies on informal firms' economic performance (Nguimkeu and Okou, 2021). Third, we find that the degree of informality, capital accumulation, and innovation behaviors are correlated with specific mobile technology uses, while no effect is found for access to credit. Hence, our results show that digital technologies hold great potential to improve small firms' efficiency and overcome some barriers they face. Our findings suggest that the number of tasks and the intensity of use play a key role in these relationships, confirming that inequalities in usage partly explain performance differences observed among small informal firms.

Our chapter contributes to the literature on the role of digital technologies in small firms' economic performance in three ways. First, we demonstrate that addressing the complexity of the appropriation of mobile technologies allows for a deeper understanding of the diffusion of these technologies and how they can benefit small firms. The data allows us to examine 32 practices, from which we identify specific patterns associated with final and intermediate outcomes. In the context of sub-Saharan countries, only Berrou et al. (2020) and Eekhout et al. (2022), based on the first wave of the panel survey used in this chapter, adopt such multidimensional measures by identifying different profile users. Second, in addition to using a complex measure of the digital inclusion

of informal entrepreneurs in Dakar, our results are derived from an original panel data survey. It allows us to observe the dynamics of mobile technologies diffusion over time and to address some concerns about the endogeneity of the relationship under study. Indeed, we estimate panel data models with a fixed effects estimator that control for unobserved time-invariant heterogeneity of firms and entrepreneurs. It enables us to avoid omitted variable bias likely to occur as firms self-select into the user group. Third, we provide new evidence on the channels through which these technologies may affect small firms' economic performance. These types of evidence are scarce in the literature, with some empirical studies relating significant associations with firm's innovation behaviors (Cirera et al., 2016; Paunov and Rollo, 2016) or capital accumulation (De Mel et al., 2022; Riley, 2022) in developing countries. Based on these results, we argue that, in addition to the fact that digital technologies can help small firms achieve their maximum output by improving technical efficiency (Eekhout et al., 2022), they hold potential for expanding their production capacity, mainly by overcoming some important constraints they face.

We also identify some shortcomings in our empirical strategy that might be addressed in future research. First, measuring digital inclusion remains challenging. We acknowledge that our digital inclusion measurement is time-invariant, although new forms of mobile technologies usage are emerging rapidly over time. For example, in our survey, voice messages appear to be widely adopted by informal entrepreneurs in 2019, whereas they were almost absent in 2017. While this is not a significant issue over a two-year period, future surveys should regularly update the design of questions related to digital inclusion. In particular, while our measure of digital inclusion includes mainly basic uses of digital technologies, the rapid diffusion of these technologies will likely lead to more complex practices in the future. In addition, our study focuses on the professional usage of mobile technologies. The reason is that few informal entrepreneurs in Dakar had access to a computer in 2017 (9%). It is important to note that digital inclusion may manifest differently depending on the environment businesses operate in and the material equipment to which they have access. Finally, as our measure of mobile technologies

usage is self-reported by entrepreneurs, future research may provide additional evidence on how small firms may benefit from mobile technologies using mobile phone data or more direct measures. In addition, more causal evidence is also needed. Our case study provides additional robust evidence of a positive association between digital inclusion and small firms' performance but does not address all endogeneity bias. It supports the implementation of experimental approaches to orientate future policy interventions better.

Our findings have some policy implications. As digital technologies become essential tools for business management, policy interventions that aim to improve small firms' performance should consider adding a digital skills component to business training programs. Indeed, insufficient digital skills among informal entrepreneurs, principally due to limited human capital and technology familiarity, remain a major barrier to the diffusion of advanced usage. Specifically, we find that informal entrepreneurs of Dakar barely use digital technologies for internal management purposes, revealing an untapped potential regarding the multitude of tools these technologies offer. Moreover, digital technologies are at least a tool for applying business practices and, at best, a catalyst for the efficiency of such practices. Then, while our case study focuses on Dakar, one of the most dynamic regions in West Africa, advanced uses such as the internet or mobile money usage for business purposes remain low in intensity. Although mobile technologies have spread between 2017 and 2019 in the informal sector in Dakar, the affordability of these services is crucial to support their high-frequency use. Indeed, despite ongoing significant improvements, Africa remains the region with the least affordable ICT services, with very few countries currently meeting the accessibility target set by the UN Commission on Broadband for Sustainable Development of 2% of monthly gross national income per capita for entry-level broadband service (ITU, 2022). Finally, we argue that recognizing the heterogeneity of informal entrepreneurs is fundamental to effective policy interventions (Schoar, 2010), including such technology-based interventions (Bhattacharya, 2019), the effectiveness of which may vary depending on entrepreneurial orientation, firm characteristics, and current

levels of digital technologies usage. In addition, if infrastructural access to digital technologies is not a barrier to adoption in the Dakar region, spatial inequalities in cell and broadband network coverage persist within and between African countries, threatening the effectiveness of such policy interventions, specifically in rural areas.

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Appendix

Table A1: Association between mobile technologies usage and monthly value-added (FE models)

	log(Value-added)				
	(1)	(2)	(3)	(4)	(5)
log(Employee remuneration)	0.070 (0.050)	0.072 (0.051)	0.072 (0.050)	0.068 (0.051)	0.067 (0.052)
log(Physical capital assets)	0.014 (0.017)	0.017 (0.018)	0.015 (0.018)	0.016 (0.018)	0.015 (0.018)
log(Inventories)	0.004 (0.036)	0.007 (0.038)	0.009 (0.036)	0.006 (0.035)	0.007 (0.037)
Operate at home	0.220** (0.101)	0.215** (0.103)	0.206* (0.105)	0.231** (0.101)	0.226** (0.102)
Registered (NINEA)	-0.033 (0.065)	-0.024 (0.065)	-0.010 (0.063)	-0.045 (0.066)	-0.037 (0.066)
Pay formal taxes	0.116** (0.051)	0.104** (0.051)	0.109** (0.051)	0.118** (0.051)	0.123** (0.053)
Bank account	-0.025 (0.068)	-0.018 (0.070)	-0.014 (0.066)	-0.022 (0.067)	-0.021 (0.068)
Electricity access	0.048 (0.090)	0.044 (0.090)	0.044 (0.089)	0.041 (0.089)	0.042 (0.087)
Mobile total score	0.520** (0.237)				
Features score		0.193 (0.180)			-0.120 (0.250)
Intensity score			0.252** (0.120)		0.160 (0.138)
Tasks score				0.464** (0.219)	0.495* (0.284)
Smartphone	-0.085 (0.089)	-0.078 (0.105)	-0.049 (0.080)	-0.064 (0.083)	-0.048 (0.102)
Constant	12.268*** (0.511)	12.362*** (0.509)	12.393*** (0.508)	12.219*** (0.517)	12.227*** (0.519)
Firm and entrepreneur fixed effect	Yes	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes	Yes
Department fixed effect	Yes	Yes	Yes	Yes	Yes
Year x department fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	608	608	608	608	608

Notes: Coefficients of dummy variables for zero values of physical capital asset, inventory, and employee remuneration are omitted. Robust standard errors are in parentheses. *p < 0.05, **p < 0.01, ***p < 0.001. *Source:* Author's computations.

Table A2: Robustness tests for other usage aggregation methods - Monthly sales (FE models)

	(1) log(Sales)	(2) log(Sales)	(3) log(Sales)	(4) log(Sales)
log(Employee remuneration)	0.171** (0.075)	0.172** (0.074)	0.172** (0.075)	0.169** (0.075)
log(Physical capital assets)	0.068 (0.043)	0.066 (0.042)	0.068 (0.043)	0.067 (0.043)
log(Inventories)	0.029 (0.036)	0.033 (0.037)	0.029 (0.036)	0.032 (0.037)
Operate at home	0.446*** (0.151)	0.438*** (0.154)	0.446*** (0.151)	0.437*** (0.154)
Registered (NINEA)	0.074 (0.123)	0.103 (0.127)	0.074 (0.122)	0.087 (0.125)
Pay formal taxes	0.155 (0.122)	0.164 (0.120)	0.150 (0.122)	0.153 (0.121)
Bank account	0.087 (0.097)	0.089 (0.097)	0.090 (0.097)	0.093 (0.097)
Electricity access	0.014 (0.156)	0.021 (0.155)	0.013 (0.156)	0.015 (0.154)
Alternative - Total score	0.686** (0.307)			
Alternative - Features score		-0.101 (0.289)		
Alternative - Intensity score		0.615*** (0.230)		
Alternative - Tasks score		0.317 (0.282)		
First dimension - Total score			0.621** (0.313)	
First dimension - Features score				-0.077 (0.294)
First dimension - Intensity score				0.430* (0.232)
First dimension - Tasks score				0.368 (0.267)
Smartphone	-0.035 (0.124)	-0.004 (0.121)	-0.067 (0.128)	-0.023 (0.139)
Constant	9.420*** (1.034)	9.460*** (1.031)	9.461*** (1.035)	9.530*** (1.040)
Firm and entrepreneur fixed effect	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes
Department fixed effect	Yes	Yes	Yes	Yes
Year x department fixed effects	Yes	Yes	Yes	Yes
Observations	608	608	608	608

Notes: Coefficients of dummy variables for zero values of physical capital asset, inventory, and employee remuneration are omitted. Robust standard errors are in parentheses. *p < 0.05, **p < 0.01, ***p < 0.001.

Source: Author's computations.

Table A3: Robustness tests for other usage aggregation methods - Value-added (FE models)

	(1)	(2)	(3)	(4)
	log(VA)	log(VA)	log(VA)	log(VA)
log(Employee remuneration)	0.070 (0.050)	0.068 (0.052)	0.071 (0.050)	0.065 (0.053)
log(Physical capital assets)	0.014 (0.017)	0.015 (0.018)	0.014 (0.017)	0.015 (0.018)
log(Inventories)	0.004 (0.036)	0.007 (0.038)	0.004 (0.036)	0.005 (0.037)
Operate at home	0.220** (0.101)	0.232** (0.100)	0.220** (0.101)	0.235** (0.100)
Registered (NINEA)	-0.032 (0.065)	-0.039 (0.067)	-0.033 (0.065)	-0.048 (0.067)
Pay formal taxes	0.118** (0.051)	0.124** (0.053)	0.115** (0.051)	0.120** (0.052)
Bank account	-0.027 (0.068)	-0.024 (0.068)	-0.025 (0.068)	-0.022 (0.068)
Electricity access	0.048 (0.090)	0.045 (0.088)	0.048 (0.090)	0.039 (0.087)
Alternative - Total score	0.529** (0.237)			
Alternative - Features score		-0.118 (0.274)		
Alternative - Intensity score		0.179 (0.137)		
Alternative - Tasks score		0.528 (0.328)		
First dimension - Total score			0.512** (0.233)	
First dimension - Features score				-0.119 (0.235)
First dimension - Intensity score				0.047 (0.123)
First dimension - Tasks score				0.551* (0.300)
Smartphone	-0.059 (0.082)	-0.056 (0.088)	-0.087 (0.090)	-0.043 (0.103)
Constant	12.241*** (0.508)	12.197*** (0.518)	12.264*** (0.511)	12.228*** (0.524)
Firm and entrepreneur fixed effect	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes
Department fixed effect	Yes	Yes	Yes	Yes
Year x department fixed effects	Yes	Yes	Yes	Yes
Observations	608	608	608	608

Notes: Coefficients of dummy variables for zero values of physical capital asset, inventory, and employee remuneration are omitted. Robust standard errors are in parentheses. *p < 0.05, **p < 0.01, ***p < 0.001.

Source: Author's computations.

Table A4: Distribution of intermediate outcomes (2017-2019)

	2017	2019	t-Test
<i>Level of informality</i>			
Registration (NINEA)	0.14	0.19	0.064*
Pay formal taxes	0.73	0.71	0.718
<i>Credit access</i>			
Access to one million XOF	0.41	0.31	0.011**
Access to bank credit	0.07	0.12	0.053*
<i>Capital accumulation</i>			
Replacement investment	0.27	0.47	0.000***
Intensive accumulation	0.21	0.61	0.000***
Extensive accumulation	0.03	0.14	0.000***
<i>Innovation behaviors</i>			
Product innovation	-	0.60	-
Process innovation	-	0.41	-
Marketing innovation	-	0.40	-

Notes: *p < 0.05, **p < 0.01, ***p < 0.001.

Source: Author's computations.

Table A5: Association between mobile technologies usage and credit access (FE-LPM models)

	Access to one million XOF			Access to bank credit		
	(1)	(2)	(3)	(4)	(5)	(6)
Mobile total score	0.026 (0.186)			-0.005 (0.129)		
Features score		0.070 (0.181)			-0.172 (0.125)	
Intensity score		-0.196 (0.153)			-0.045 (0.104)	
Tasks score		0.087 (0.206)			0.198 (0.124)	
Function score - Bilateral coordination			0.055 (0.106)			0.007 (0.069)
Function score - Multilateral coordination			-0.042 (0.116)			0.081 (0.076)
Function score - Financial			-0.019 (0.085)			-0.005 (0.058)
Function score - Internal management			0.168 (0.141)			0.006 (0.088)
Smartphone	-0.066 (0.069)	-0.074 (0.071)	-0.075 (0.069)	0.031 (0.043)	0.057 (0.046)	0.018 (0.042)
Inputs factors	Yes	Yes	Yes	Yes	Yes	Yes
Time-variant firm's characteristics	Yes	Yes	Yes	Yes	Yes	Yes
Firm and entrepreneur fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Department fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Year x department fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	608	608	608	608	608	608

Notes: Robust standard errors are in parentheses. *p < 0.05, **p < 0.01, ***p < 0.001.

Source: Author's computations.

Table A6: Association between mobile technologies usage and extensive capital accumulation (FE-LPM models)

	Extensive accumulation		
	(1)	(2)	(3)
Mobile total score	0.095 (0.148)		
Features score		0.097 (0.115)	
Intensity score		-0.046 (0.112)	
Tasks score		0.022 (0.142)	
Function score - Bilateral coordination			-0.003 (0.066)
Function score - Multilateral coordination			0.105 (0.080)
Function score - Financial			0.054 (0.056)
Function score - Internal management			-0.174** (0.082)
Smartphone	-0.032 (0.036)	-0.043 (0.039)	-0.023 (0.036)
Inputs factors	Yes	Yes	Yes
Time-variant firm's characteristics	Yes	Yes	Yes
Firm and entrepreneur fixed effect	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes
Department fixed effect	Yes	Yes	Yes
Year x department fixed effects	Yes	Yes	Yes
Observations	608	608	608

Notes: Robust standard errors are in parentheses. *p < 0.05, **p < 0.01, ***p < 0.001.

Source: Author's computations.

Table A7: Association between baseline mobile technologies usage and marketing innovation in 2019 (Probit models)

	Marketing innovation		
	(1)	(2)	(3)
Mobile total score	0.105 (0.149)		
Features score		0.269 (0.168)	
Intensity score		-0.152 (0.141)	
Tasks score		-0.076 (0.073)	
Function score - Bilateral coordination			-0.033 (0.106)
Function score - Multilateral coordination			0.065 (0.098)
Function score - Financial			0.053 (0.079)
Function score - Internal management			-0.083 (0.133)
Smartphone	0.112 (0.070)	0.076 (0.073)	0.125* (0.069)
Inputs factors	Yes	Yes	Yes
Yes	Yes	Yes	
Firm's and entrepreneurs characteristics	Yes	Yes	Yes
Yes	Yes	Yes	
Department fixed effect	Yes	Yes	Yes
Yes	Yes	Yes	
Observations	608	608	608
608	608	608	

Notes: Average marginal effects from probit estimation. Robust standard errors are in parentheses. *p < 0.05, **p < 0.01, ***p < 0.001.

Source: Author's computations.

General Conclusion

The ongoing spread of digital technologies is profoundly reshaping the technological environment in developing countries, creating new challenges and opportunities to accelerate progress towards sustainable and inclusive development (Choi et al., 2020). This thesis sheds light on the related implications for informal businesses in sub-Saharan Africa, whose importance in generating livelihoods for millions of individuals persists despite two decades of growth (Ohnsorge and Yu, 2022). It offers further empirical evidence on how informal businesses are adopting digital technologies and benefiting from the digitalization of parts of their business activities. In contrast with the techno-deterministic view, the thesis assumes that the effects of digital technologies depend mainly on how individuals appropriate them, which is, in turn, socially determined. All three chapters therefore focus on the use of digital technologies, and aim to reveal the complexity of the digital inclusion process taking place in informal sectors in sub-Saharan Africa.

This thesis provides several analytical and empirical contributions to the literature on the digital inclusion of informal firms, by investigating this phenomenon further and deepening understanding of its implications. In line with the conceptualization of professional uses of mobile technologies provided by Berrou et al. (2020), the empirical analysis presented in this thesis considers the adoption of digital technologies as a complex process, leading to diversified forms of appropriation (Ragnedda et al., 2022). It provides a more in-depth description of digital inequalities occurring in informal sectors of sub-Saharan African countries. While analysis of the determinants of disparities in the use of digital technologies among informal enterprises is often

limited to the socio-demographic traits of users in the literature (Atiyas and Dutz, 2023; Eekhout et al., 2022), the thesis confronts the level of digital inclusion with the structural heterogeneity of informal sectors (Bhattacharya, 2019). Furthermore, it also provides new empirical evidence on the potential of professional uses of digital technologies to boost informal firms' economic performance. It adds to the existing literature by unraveling the complexity of that relationship (Danquah and Owusu, 2021; Atiyas and Dutz, 2023; Eekhout et al., 2022). Throughout the thesis, all dimensions of technology appropriation are examined, from specific functions to modalities of their implementation by firms. While the empirical analysis estimates their effects on conventional performance outcomes such as sales, value-added, and profits, the thesis also extends the study of this relationship to firms' dynamic outcomes, including survival and sales growth. In addition, mediation analyses are carried out to highlight some mechanisms at work behind the performance-enhancing effects of digital technologies. This includes probing the potential channels associated with changes in the firm's trading network, its access to capital and credit, its degree of informality, and its innovation capacity. While the direct influence of digital technologies uses on informal firms' performance has been examined in the literature, such underlying channels of influence have remained largely unexplored. Finally, the detailed exploration of informal firms' digital inclusion is made possible by access to second-hand data (Research ICT Africa, 2020), which allows for a cross-country analysis. The empirical evidence is also based on first-hand data from a panel survey designed to answer these specific questions in the case study of Dakar's informal sector.

The dissertation follows a progressive approach structured in three chapters that provide original empirical evidence on key issues related to the digital inclusion of informal firms. **Chapter 1** investigates the existence and determinants of digital inequalities, one of the main concerns of policymakers about the spread of digital technologies. Specifically, two specific questions related to the diffusion of digital technologies within informal sectors of sub-Saharan African countries are addressed: Do informal firms in sub-Saharan Africa use these technologies for business purposes? Does the spread of digital technologies

conceal digital inequalities in usage within African informal sectors? The analysis relies on the After Access business surveys, conducted by Research ICT Africa (2020) in 2017-18 among 3,300 firms and entrepreneurs in eight sub-Saharan African countries²⁹. The descriptive evidence shows that informal entrepreneurs widely own mobile phones (79%) and use digital technologies for business purposes (65%). However, micro-sized firms in sub-Saharan Africa appear to mainly rely on digital technologies for bilateral coordination with their suppliers and customers, with the appropriation of more advanced usage, such as the internet, mobile money, and management software, still in their early stages. In addition to significant disparities across countries, our findings reveal the existence of substantial digital inequalities between informal firms, that align with the vertical heterogeneity of informal sectors in sub-Saharan Africa. The lower tier of survivalists is the most digitally excluded regarding ICT device ownership and professional usage. Conversely, the most successful firms, the so-called top performers, largely embrace digital technologies in their way of doing business. Despite being almost as well equipped and having similar socio-demographic characteristics and entrepreneurial behaviors as top performers, firms in the intermediate segment still exhibit a lower level of digital technologies usage than the most successful firms. Hence, these inequalities are strongly associated with pre-existing socio-economic inequalities, reinforcing the exclusion of those who are already the most excluded. Findings show that the disparities in the use of digital technologies by gender and educational attainment observed at the individual level persist in the productive sphere. In addition, firms with the highest level of informality, low profits, precarious operating conditions, no access to financial services, and less developed value chains are less likely to use digital technologies. Addressing digital inequalities appears to have common and segment-specific levers. The decomposition results show that subsistence entrepreneurs face significant barriers in the successive phases of digital technologies appropriation. These barriers include motivation, material access, skills, and the affordability of digital services. In contrast, the second-level digital divide between constrained gazelles and top performers seems to primarily stem from their reduced capacity to afford digital services.

²⁹Senegal, Ghana, Nigeria, Rwanda, Kenya, Tanzania, Mozambique, and South Africa.

Based on the observation that informal firms mainly rely on digital technologies for market coordination with suppliers or customers, **Chapter 2** aims to empirically investigate whether and how these uses affect informal firms' economic performance. Using an instrumental strategy, this chapter shows that sales, value-added, and net profit are significantly higher for informal businesses that use digital technologies to communicate with their trading partners than non-users. These findings confirm the overall enhancing effect of access to and use of digital technologies on firms' performance documented in the literature, and specifically the central role of bilateral coordination practices (Eekhout et al., 2022; Berrou et al., 2020). While the spread of advanced uses such as mobile money and the internet is promising, the most basic communication uses affect informal firms' sales by significantly reshaping their trading network. On the one hand, non-farm informal firms may benefit from digital technologies diffusion through better market access. Indeed, user firms are likely to have more suppliers, formal partners, and trading partners located further away than the surrounding villages and towns than non-users. On the other, firms implementing digital technologies in their business interactions appear to have greater strength of ties in their upstream value chain (Berrou and Combarrous, 2012), inducing a reduction in transaction costs and better access to relational contracting (Rudder, 2020). All informal firms appear to benefit to the same extent from this usage, regardless of the entrepreneur's gender, the firm's location, its level of informality, or its size, highlighting the absence of a third-level digital divide for this usage (Scheerder et al., 2017). However, the quantile estimates indicate that the positive effects of digital bilateral coordination on informal firms' sales are only significant below the 80th percentile of the sales distribution. Given the significant inequalities in access and usage observed within this population, it demonstrates that once the initial barriers to usage have been overcome, all informal firms, and notably the most vulnerable, can benefit from the most basic uses of digital technologies to the same relative extent.

The cross-country survey used in the first two chapters does not allow further investigation of the role of digital technologies appropriation in performance disparities

observed among informal firms. To fill this gap, **Chapter 3** presents a case study on the informal sector of the Dakar region in Senegal using first-hand data from a panel survey. This region is one of the most dynamic areas of West Africa and displays an advanced stage of digital technologies diffusion (Berrou et al., 2020). The survey data allows us to adopt a more detailed measure of digital technologies appropriation, comprising 32 questions relating to the diversity of functions, the range of features, and the intensity of uses. The results show that mobile technologies usage may affect informal firms' business operations in a complex but extensive way. We find that baseline overall appropriation of digital technologies does not significantly predict higher survival rates and faster sales growth over the period 2017-2019. However, firm survival is correlated with higher bilateral coordination usage at baseline, while subsequent evolution of digital technologies usage appears to be significantly and positively associated with sales growth patterns. In addition, more advanced appropriation of these technologies is significantly associated with higher sales and value-added in the informal sector of Dakar. These findings suggest that the diversity of functions and the intensity of use play a key role in these relationships, confirming that inequalities in usage partly explain performance differences observed among small informal firms. Some intermediate outcomes through which mobile technologies usage may affect small firms' performance are identified. Findings show that firms using mobile money are more likely to be registered. In contrast, we find that firms using mobile technologies for internal management purposes are less likely to pay formal taxes, probably due to a greater ability to dissimulate or misreport their level of activity to local authorities. Despite the lack of effect on access to credit, mobile money and internal management practices also seem to facilitate replacement investment and intensive accumulation, probably by improving the financial management and savings capacity of informal firms. Finally, the use of the internet predicts the firms' implementation of process and product innovation. At the same time, mobile money usage is also associated with introducing new or improved goods or services. Based on these results, we argue that digital technologies not only help small firms achieve their maximum output by improving technical efficiency (Eekhout et al., 2022),

but also offer the potential to expand their production capacity, mainly by spurring capital accumulation and innovation capacity.

These findings carry important policy implications. Despite significant progress in the roll-out of telecommunication infrastructures in sub-Saharan Africa, the adoption of these new technologies is uneven across the population, profoundly rooted in pre-existing socio-economic inequalities. The informal sectors are no exception, as this new technological dimension exacerbates the exclusion already experienced by subsistence entrepreneurs, and risks to dig the gap between the most successful firms and those in the intermediate segment. To prevent the most vulnerable from being left behind and exploit the full potential of digital transformation, a policy agenda is needed to spur the digital inclusion of informal firms and workers. While tackling supply-side constraints, such as infrastructural access and affordability of digital services, must remain a political priority in sub-Saharan Africa, more specific interventions targeting the accessibility of digital technologies for informal businesses can be envisaged. To date, entrepreneurship training programs rarely include technology adoption or digital skills training (Quinn and Woodruff, 2019), although the accumulating empirical evidence on their welfare-enhancing effects makes it a contemporary necessity. By targeting specific fringes of informal firms, digital skills training could tackle digital inequalities that emerge among small firms in sub-Saharan Africa, but also encourage the adoption of more advanced usage. The findings show that informal firms with intensive and diversified use of digital technologies in their business activities significantly outperform those with a low level of digital technologies appropriation. This result is intrinsically tied to the well-known importance of business practices in explaining differences in the performance of small businesses (McKenzie and Woodruff, 2017). We argue that digital technologies can facilitate such business practices and catalyze their efficiency through the support and new opportunities they provide to entrepreneurs. However, although digital technologies can empower informal firms in many dimensions, they alone cannot address the systemic constraints that hamper informal firms' growth. Policies aiming to help informal firms reap the efficiency and productivity gains offered by digital technologies need to integrate

a policy mix, that still includes traditional interventions targeting specific economic, social, or institutional constraints. The widespread ownership of mobile phones by informal entrepreneurs also offers new opportunities for public policies to reach these groups, who have traditionally been beyond the scope of the authorities. However, digital-based policy interventions for informal enterprises must also acknowledge that selection bias may occur due to digital inequalities, most vulnerable people being inaccessible or unable to benefit from interventions via their own digital devices.

This thesis emphasizes the need for focused attention and tailored strategies to bridge the digital divide and harness the potential of digital technologies for informal enterprises in sub-Saharan Africa. However, some shortcomings call for future research in this field. First, measuring the use of digital technologies remains challenging. As the data on usage used throughout the thesis is self-reported by entrepreneurs, estimates of professional use of digital technologies may be biased upwards or downwards. Future research could draw on more direct measures, such as mobile data, although it implies other challenges, such as the inability to dissociate professional and personal uses. Second, the relationship between the professional usage of digital technologies and firms' performance is endogenous. Throughout the thesis, empirical strategies have attempted to address this endogeneity bias to provide robust empirical evidence. However, to design evidence-based policies, randomized experiments to determine whether small businesses can be induced to adopt specific functions of digital technologies, and whether they will benefit from doing so, are required (Nguimkeu and Okou, 2021). Such randomized experiment is currently implemented in Egypt among small firms with a specific focus on digital marketing (McKenzie et al., 2021). Third, identifying barriers to digital use among informal firms remains crucial. In particular, evidence on the level of digital skills of informal entrepreneurs is lacking. Measuring digital skills in the informal sector would help to unveil whether this lack of internal resources further explains disparities in usage across segments, as suggested by the results of this thesis.

Finally, other empirical studies on how digital technologies affect informal activities, in other contexts or focusing on specific dimensions of business activities, may provide

additional insights. For this purpose, several empirical analyses using the panel survey on the informal sector in Dakar are in progress. Based on an innovative adaptation of the multiple name generator method (Marsden, 2005), which gathers detailed information on entrepreneurs' frequent mobile contacts, ongoing work seeks to unveil how mobile technologies interact with the complex structure of informal entrepreneurs' social networks (Berrou and Combarnous, 2012). The first empirical analyses confirm that a higher proportion of professional mobile contacts is associated with better economic performance, and tend to show that most successful firms are engaged in decoupling their professional relations from interpersonal ones. Furthermore, to investigate the role of digital technologies during the Covid-19 crisis, we have collected a third survey wave in 2022 in the informal sector of Dakar. Empirical evidence shows that the digital inclusion of informal businesses is an ongoing process, as those that have not ceased their activity continue to expand and intensify their use of digital technologies (Berrou et al., 2023). Furthermore, preliminary results show that advanced users were more resilient to the shock associated with the Covid-19 restrictions, confirming the central and growing impact of digital technologies on informal activities in sub-Saharan Africa.

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