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The impact of network coverage on adoption of Fintech and financial inclusion in sub-Saharan Africa

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Abstract

Digital finance plays a major role in improving access to, usage and quality of financial services in developing countries. The use of these platforms has been associated with a positive impact on economic growth and people's welfare. They allow for convenient, secure, and efficient transaction and are the crucial element of e-commerce. In this paper, we analyse the effect of mobile network coverage on adoption of financial technologies and financial inclusion using a survey data of 12,735 individuals from nine sub-Saharan African countries conducted in 2017. By combining survey data with information on the proximity of mobile network towers, we estimate a two-stage model. In the first stage, consumers decide to adopt a technology device, and in the second stage, they decide whether to use digital financial services or not. Results show a significant and positive relationship between network coverage and adoption of digital financial services. Considering that the whole population lives within 2 km radius from the LTE tower, financial inclusion would increase by 6% in Mozambique and 3% in Ghana, Rwanda and Senegal. In Tanzania, where mobile money is the common financial service, investment in GSM and UMTS would have a larger impact on financial inclusion than LTE. These results show that digital financial technologies such as mobile money, mobile banking and e-wallet, that do not necessarily require consumers to be connected to the Internet have a greater impact on financial inclusion in East African countries, where financial service innovations are mobile led. However, in countries where digital financial innovations are bank led, LTE coverage have a greater impact than GSM and UMTS coverage. The findings of this study can help policy-makers to understand the issues related to the expansion of digital financial services and effective strategies to deliver these services to the poor.

Keywords: Digital finance, Digital technologies, Financial inclusion

JEL Classification: C18, D12, L11, L21, L22, L51

1 Introduction

Empirical research has shown that adoption of mobile phones and the Internet have a remarkable input on economic growth performance. Roller and Waverman (2001); Pohjola (2002); Jalava and Pohjola (2002) identify a few potential mechanisms through which Internet and mobile phones, specifically smartphone, can stimulate economic growth. First, it accelerates productivity and innovation by improving access to information and reducing search costs. Second, it improves social-wellbeing through increased social interaction (Jorgenson et al. 2008). In Africa, where more than 33 percent of the population live in extreme poverty, and 36 percent are illiterates, adoption of mobile phones and Internet has a potential to serve as a virtual infrastructure for provision of services which are generally not available to poor people. The proliferation of mobile devices has increased adoption of digital services amongst remote area dwellers and increased access to online education and programmes, health, agricultural programmes and digital finance. The current study focuses on the role of investment in mobile network infrastructure for broadening access and use of digital financial services in nine sub-Saharan Africa countries, an area which is not critically addressed in the literature.

Digital finance includes all financial services that are provided through mobile phones, personal computers, the Internet or cards linked to a reliable digital system. It encompasses a host of financial products and services delivered by Fintech companies and innovative financial services providers including mobile network providers, banks and finance-related software companies (Ozili 2018). These platforms enable individuals and companies to have access to payments, savings and credit facilities without the need to visit a motor and brick bank branch (Mothobi and Grzybowski 2017). Digital finance can increase the speed and reduce the cost of payments. It has also been found to enhance security due to increased transparency through digital accounting and can provide an entry point into the formal financial system whilst at the same time promote increased saving and allow users to smooth consumption against small adverse shocks (Demirguc-Kunt et al. 2018).

Digital financial services provide an opportunity to promote financial inclusion through innovative and cheaper platforms that links the poor people with providers of savings, credit and insurance products (Radcliffe and Voorhies 2012). In this context, financial inclusion means that individuals and businesses have access to affordable financial products and services—payments, transactions, savings, credit and insurance (Sarma and Pais 2011). Digital finance platforms have opened doors for the poor, who were previously excluded from orthodox financial systems, to have access to payments systems, savings and credit facilities via online and mobile phone financial services without the need to have a bank account or visit a bank branch (McKee et al. 2015).

The banking sector in sub-Saharan Africa remains underdeveloped. Based on a survey conducted by Research ICT Africa, which we use in this paper, majority of people living in sub-Saharan Africa countries are financially excluded. As of 2017, only 29% of people in nine sub-Saharan African countries had a bank account. This number is much below the average for developing countries worldwide. However, the introduction of digital platforms and more specifically mobile money services have contributed significantly to increased financial inclusion amongst developing countries. For instance, Demirguc-Kunt et al. (2018) find that between 2014 and 2017, the share of adults who have an account with a financial institution or through mobile phone rose globally from 62 to 69%. In high-income countries 94% of adults have an account, whilst in developing economies 63% do. Based on the mentioned survey by Research ICT Africa, financial inclusion rose from less than 20% in 2011 to more than 50% in 2017. The main reasons for low levels of formal bank account in Africa are infrastructure deficits, inaccessibility and financial illiteracy (Mothobi and Grzybowski 2017).

The Internet and mobile phone-based technologies can change this situation by enabling the excluded to make use of digital financial services. In this way, they can overcome the problem of poor infrastructure and expensive traditional banking model, which relies on a network of physical branches. Despite the evidence that financial technologies have the potential to solve the persistent financial exclusion problems in developing countries, studies that investigate the effect of mobile network coverage on financial inclusion are very scarce. Amongst the few studies, Grzybowski et al. (2023b) find that there is less mobile money usage in areas that are less developed economically and individuals who live in less developed areas are less likely to send but more likely to receive money via their mobile money wallet. This study tries to fill this gap by examining how availability of mobile network coverage influences adoption of financial technologies and how investments in network coverage might impact financial inclusion. Taking into consideration the differences in network technologies, with urban areas more likely to have high-speed technologies, the study contributes to the literature by providing insights on how different technologies are likely to drive financial inclusion.

The current study differ with the existing literature in threefold. First, the study models the use of financial services as a two-state procedure, to account for sample selection. Second, whilst majority of the literature that study the impact of technologies on financial inclusion focuses on adoption of mobile phones, in this particular study, we consider digital devices which include mobile phones, computers and access to Internet, and last, the study aims to investigate how different network technologies impact financial inclusion. Hence, this study is unique and provides an opportunity to disentangle how different technologies affect adoption of financial services. Results obtained from this study can be generalised to other Sub-Saharan countries, which have similar characteristics with surveyed countries. Moreover, the findings of this study can help policy makers to understand the issues related to the expansion of digital financial services and effective strategies to deliver these services to the poor.

Despite the importance of digital finance platforms, there is a very small body of literature that investigates the use and adoption of digital finance in developing countries. Most existing studies have focused on the use of mobile money service with particular attention given to M-Pesa in Kenya, and some other East African countries (see for instance Jack et al. (2013); Mbiti and Weil (2013); Munyegera and Matsumoto (2016)). The literature that analyses the role of infrastructure availability on financial inclusion is very scarce but developing. The scarcity of this literature is mainly due to lack of data that is able to measure the level of development at micro-level. Amongst the few studies, Mothobi and Grzybowski (2017) analyse how the level of infrastructure at the place of residence influences adoption of mobile money. This research adds to this literature by analysing the effect of mobile network infrastructure on adoption of digital platforms for financial transactions. For this analysis non-binary measures of development are used to investigate how availability of mobile network infrastructure influences financial technology services.[1]

This study is motivated by a new and developing literature that investigate the role of infrastructure availability on adoption of innovative financial services. A dominant theme in this literature is that individuals who live in areas with poor infrastructure rely on financial technologies to conduct financial transactions. For instance, Mothobi and Grzybowski (2017) conclude that mobile phone has the potential to improve the livelihoods of people living in rural areas by providing them with access to financial services which are generally not available physically. In that sense, mobile networks have the potential to broaden financial services to areas that are not covered by physical bank branches. Perlman and Wechsler (2019) find that the adoption of digital financial services has improved financial inclusion in developing countries. These services are found to provide the unbanked and underserved with access to basic financial services. The examination of how availability of mobile network infrastructure influences the adoption of financial technologies, which is the focus of this paper, is an important contribution to the literature. This literature provides new insights on how availability of mobile network infrastructure may promote financial inclusion.

The study contributes to existing literature on mobile coverage and financial inclusion using a geo-referenced nationally representative survey data covering nine African countries—Ghana, Kenya, Mozambique, Nigeria, Rwanda, Senegal, South Africa, Tanzania and Uganda. We use the GPS coordinates to match the survey data which collects information on ICT access and use by households and individuals to the GPS coordinates of towers. Using the coordinates, the Euclidean distance is then used to measure how far a household is to various infrastructural variables such as Global System Mobile (GSM) communication, Universal Mobile Telecommunication System (UMTS), Long-Term Evolution (LTE) and other variables that measure the level of development within the location at which a household is situated.[2]

In our data we have individuals who do not own a digital device (mobile phones, laptop and computers) to access digital financial technologies. Since people who own devices are selected non-randomly from the population, estimating the determinants of digital financial technologies from the subpopulation of those who have the access devices may introduce bias and lead to erroneous conclusions. To correct for this, a two-step Heckman correction model is used for sample selection bias.

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[1] Prior studies often use 0–1 categorical variables such as urban or rural to measure the level of development. However, in this study we use continuous variables such as proximity to a tower to measure the level of development at the location of household. Other studies use night-time light intensity, distance to a bank, road and night-time light intensity to measure the level of development at a location of household (see Grzybowski et al. (2023b)).

[2] UMTS is a third-generation mobile cellular system for networks based on GSM standard, which support 2G and 2.5G, whilst LTE can support 4G communication with better speed compared to UMTS. Thus, distance to tower is used to measure network coverage. Moreover, the data allow for differentiation of mobile network towers according to their ability to support different generation such as 2G, 3G and 4G networks.

Using a series of heckprobit model specifications, where in the first stage consumers decide whether to adopt a digital device or not and in the second stage those who have adopted a digital device decide to use a financial digital platform or not, we find that mobile network coverage positively influences financial inclusion, with individuals living near towers more likely to adopt digital financial services. Counterfactual simulations show that if the entire population lives within 2 km of network towers, the adoption of digital financial services would increase by an average of 2%.

Our results suggest that digital financial technologies such as mobile money, mobile banking and e-wallet, that do not necessarily require consumers to be connected to the Internet, have a greater impact on financial inclusion in East African countries. These platforms serve as a substitute to a bank account for the poor and a compliment for those with a bank account. The study reveals that financial inclusion inequalities remain influenced by income, education, location, and employment status.

The remainder of the paper is organised as follows. In Sect. 2 we discuss the state of digital finance and financial inclusion in sub-Saharan Africa countries. Section 3 reviews the literature whilst Sect. 4 discusses the datasets used in the paper. Section 5 introduces the econometric model and Sect. 6 presents the estimation results. Finally, Sect. 7 concludes.

2 Digital finance and financial inclusion in Africa

The rise of new technologies and innovative business models have disrupted the traditional banking system and provided alternative ways of providing financial services to different segments of the population, especially those who were previously excluded. Between 2011 and 2014, the number of individuals with a bank account increased by 700 million.[3] Data from the World Bank show that as of 2017, 1.2 billion adults worldwide have gotten access to an account since 2011. Today, 69% of adults have an account. However, about billion adults, or 31 percent of all adults worldwide are still unbanked, with the vast majority of them living in developing economies, where 46 percent of adults are unbanked, compared with just 6 percent of adults in high-income economies.[4]

The current COVID-19 pandemic has amplified the urgency of utilizing fintech to keep financial systems functioning and keep people safe during the times of social distancing, falling demand, reduced input supply, tight credit conditions and a rise in uncertainty. Whilst the digital platforms such as Internet banking are on the rise in developed countries, the use of Internet banking is still very low in the Africa. This is mainly due to the low levels of Internet use in these countries, especially in Africa. Just an elite of individuals who have access to the Internet can access these platforms, more specifically Fintech services that are routed through the Internet. For instance, less than a third (27%) in Africa. However, in contrast to the African and Asian countries, the Latin American countries have reached the critical mass,[5] with about 75% of adults amongst the surveyed Latin American countries using the Internet. Amongst individuals who have

[3] https://documents.worldbank.org/en/publication/documents-reports/documentdetail/187761468179367706/the-global-findex-database-2014-measuring-financial-inclusion-around-the-world.

[4] https://www.worldbank.org/en/topic/financialinclusion/overview.

[5] Critical mass in adoption of digital technologies is obtained when enough members of a society or community have adopted an interactive innovation so that the further rate of adoption becomes self-sustaining.

access to the Internet where only a small proportion transact online via online stockvel (8%), online betting (4%) and financial transaction with the government (4%).

The most common form of digital finance in sub-Saharan Africa is the M-Pesa, which is a mobile money transfer and micro-financing service launched in 2007 by Vodafone in Kenya for the operators Safaricom and Vodacom. It enables users to cash-in money using a mobile account (referred to as wallet) that is linked to a unique mobile phone number of a subscriber. It also allows accessing a wide range of services such as domestic and international money transactions, payments for bills, flights, hotels and airtime top-up (see Morawczynski and Miscione (2008)). M-Pesa is not only most common in Eastern African countries, such as Kenya, Uganda and Tanzania, Rwanda and Burundi, but it has also expanded to other African countries such as Cote d'lvore, Senegal, Madagascar, Mali, Niger, Botswana, Cameroon and South Africa. Outside of Africa, M-Pesa operates in Afghanistan, Jordan and other countries. Several banks in Africa have also rolled out a similar service called e-wallet. E-wallet differs from M-Pesa in that it requires the sender to have a bank account even though the receiver can only withdraw cash in ATM using their mobile phone number and a personal identification number (PIN), which is sent to their mobile phone. At present mobile money supports electronic payments, airtime top up/transfer, mobile banking, digital lending, international remittances and fintech.

3 Literature review

The literature on financial inclusion is relatively new but growing rapidly (see, for instance, Honohan (2008); Demirgüç-Kunt and Klapper (2012); Sarma (2016)). These studies have relied mostly on financial inclusion indices. For instance, Honohan (2008) provides a measure financial inclusion by econometrically estimating the proportion of adult population/households using formal or semi-formal financial intermediaries for 162 countries. The estimates are constructed by combining information about the number of accounts at commercial banks and at micro-finance institutions together with banking depth and GDP data. These estimates might effectively quantify one aspect of financial inclusion, that is, financial penetration. Such a measure of financial inclusion, however, has many deficiencies since several crucial aspects of an inclusive financial system are ignored, including availability, affordability, quality and usage of the financial services that together form an inclusive financial system (Sarma 2016). Furthermore, a number of studies have shown that merely having bank accounts may not be sufficient to imply financial inclusion if there are some barriers or limitations preventing people from adequately using the accounts, such as remoteness of bank branches, cost of transactions, psychological barriers (see, for instance, Kempson et al. (2004); Diniz et al. (2012)).

The second strand of literature falls on examining the determinants of financial inclusion (see, for instance, Fungáčovà and Weill (2015); Allen et al. (2016); Zins and Weill (2016)). For instance, based on the 2012 World Bank Global Findex Database on 98 developing countries, Demirgüç-Kunt et al. (2013) finds that gender matters for financial inclusion. The study shows evidence of a significant gender gap existing in account ownership, formal saving and formal credit. The likelihood of being financially excluded increases with being a woman. Zins and Weill (2016) perform probit estimations on the World Bank's Global Findex database for 37 African countries. The empirical results indicate that male, richer, more educated, and older individuals, to a certain extent, are more likely to be financially included, with a higher influence of education and income. Basically, mobile banking and traditional banking have the same determinants. However, these studies have failed to account for remoteness of bank branches, cost of transaction and proximity of the bank branches. Allen et al. (2016) also utilised the 2012 World Bank Global Findex Database to explore the individual and country characteristics associated with financial inclusion on a global scale. They find that greater financial inclusion is related to lower banking costs, greater proximity to financial intermediaries, and better institutions such as stronger legal rights, and more politically stable environments. Furthermore, being richer, more educated, older, urban, employed, married or separated individuals are shown to favour financial inclusion in terms of having an account at a formal financial institution. The same individual characteristics are also linked with the increased probability of saving formally. Finally, the probability of borrowing formally is higher for older, educated, richer and married men. This literature, however, does not consider the effect of digitisation and availability of infrastructure on financial inclusion.

There is another growing body of literature that investigates how the adoption of mobile phones and M-Pesa has impacted financial inclusion in low-income countries. For instance, Mbiti and Weil (2013) use two waves of individual level data on financial access to analyse the use and economic impact of M-Pesa in Kenya. They find that accelerated use of M-Pesa lowers the propensity of people to use informal savings mechanism but raises the probability of being banked. Whilst their results suggest that M-Pesa improves individual welfare by promoting banking and increased transfer, they find little evidence that people use M-Pesa accounts to store wealth. Jack et al. (2013) also use two waves of panel data on 3000 households in Kenya to test transactional networks and whether M-Pesa users make different kinds of transactions. They conclude that households with M-Pesa users exhibit more remittance activity than those without. They also find that households that use M-Pesa are more likely to remit for routine support, credit and insurance purposes. They conclude that mobile money allows households to spread risk more efficiently through deeper financial integration and expanded informal networks. Murendo et al. (2018) assess social network effects on mobile money adoption amongst rural households in Uganda. They find that mobile money is positively influenced by the size of social networks. In another paper, Munyegera and Matsumoto (2016) use a panel data on 846 rural households to analyse adoption of mobile money, remittances and household welfare in Uganda. They find a positive and significant effect of mobile money access on household welfare. Similar to Jack et al. (2013), they conclude that households that use mobile money are more likely to receive remittances than non-user households. They also find that the total value of remittances received by households that use mobile money is significantly higher than of non-user households. Other studies focuses on how regulatory framework affects mobile money usage. Gutierrez and Singh (2013) use data on 37,000 individuals from 35 countries to analyse determinants of mobile banking usage, with a particular focus on the regulatory framework. They conclude that a supporting regulatory framework is associated with higher usage of mobile banking for the general public as well as for the unbanked. Lashitew et al. (2019) adopt a mixed method approach, using quantitative and qualitative research methods to analyse the development and diffusion of mobile money innovations across and within countries. They find that supportive regulatory framework played a key role in guiding innovations and accelerating mobile money diffusion in Kenya. Using a qualitative approach, Bourreau and Valletti (2015) asses the economic features of digital payment systems in developing countries. They conclude that mobile money has the potential to drive financial inclusion of poor households at low cost.

The body of literature that analyses how availability of infrastructure influences adoption of mobile phone and mobile money services is scarce. Mothobi and Grzybowski (2017) combine a micro-level survey data for 11 African countries with night-time light intensity to assess the effect of infrastructure on adoption of mobile phones and mobile money services. They find a positive and significant relationship between adoption of mobile phones and availability of infrastructure. Their results also show that individuals who live in areas with poor infrastructure are more likely to use mobile phone for financial transactions. They conclude that mobile phones improve the livelihood of individuals residing in remote areas. The current study contributes to this literature by analysing the effect of digitisation on financial inclusion with a particular focus on examining how availability of Internet infrastructure and Internet use influence financial inclusion. Moreover, the study add to existing literature by assessing how proximity to a bank branch and other complementary infrastructure influence financial inclusion. We use non-binary measure of development to investigate how availability of infrastructure influences the uptake of financial services.[6]

We estimate the determinants of using financial services based on individual survey conducted in nine sub-Saharan African countries in 2017 and Heckman's sample selection model. In our data we have individuals who do not own a digital device (mobile phones, laptop and computers) to access digital financial technologies. Since people who own devices are selected non-randomly from the population, estimating the determinants of digital financial technologies from the subpopulation of those who have the access devices may introduce bias and lead to erroneous conclusions. To correct for this, a two-step Heckman correction model is used to correct for sample selection bias.[7]

In particular, we analyse how spatial differences in digital infrastructure impact the adoption of various financial services. The survey data contain exact GPS coordinates of respondents, which allows us to complement it with variables approximating infrastructure and economic development on geographic level. We use a unique data constructed by combining a nationally representative household and individual survey for nine African countries with geo referenced information for an inventory of network towers [LTE/4G, UMTS (3G)]. Using GPS coordinates, we calculate household distance from these towers. Based on a standard neoclassical utility maximisation framework, we jointly examine the determinant of account ownership and the type of account used through the use of the standard sample selection model proposed by Heckman (1979).

[6] In another study, Grzybowski et al. (2023a) investigate the effects of non-exclusive agreements between networks of mobile money agents on mobile network operator choices.

[7] See Deschacht and Goeman (2015) for further discussions on Heckman's sample selection approach.

Table 1 Adoption of mobile phones, smartphones, mobile money and bank accounts

Country	Devices		Digital	Financial			N
	Internet (%)	Smartphone (%)	Finance (%)	Mobile money (%)	Bank (%)	Card (%)	
Ghana	25.9	25.8	55.7	51.6	30.6	8.03	1196
Kenya	36.4	33.6	88.1	80.5	42.2	19.9	1216
Mozambique	20.3	17.0	25.2	23.9	24.4	20.6	1220
Nigeria	29.7	16.5	6.3	2.49	38.2	31.0	1804
Rwanda	14.2	10.7	34.2	33.9	32.7	8.96	1217
Senegal	32	22.1	35.3	32.8	10.6	4.7	1233
South Africa	45.7	43.9	21.3	7.58	57.2	33.2	1794
Tanzania	22.2	20.3	55.5	55.4	17.4	10.6	1200
Uganda	32.04	13.2	46.7	47.8	2.7	6.79	1855
Total	28.2	22.8	38.5	34.8	28.9	17.0	12735

Source: Author's own calculation based on data sources explained in Sect. 4.1

4 Data

4.1 Data sources

We combine a few different datasets to investigate the influence of availability on adoption of digital finance technologies and financial inclusion in this paper. The first dataset includes a representative individual and household surveys, which were conducted in 2017 by Research ICT Africa in the following nine African countries: Ghana, Kenya, Mozambique, Nigeria, Rwanda, Senegal, South Africa, Tanzania and Uganda.[8] The survey was conducted using electronic Android tablets and an external GPS device, which was used to capture the exact coordinates of the household. We use the geographic coordinates to merge the survey with the other datasets including information on the availability coverage and proximity to mobile network antennas.

The second database on the cell tower location was downloaded from OpenCelliD.[9] Beside the exact geo-location of each cell, the date of creation and the kind of technology can be observed: GSM (2G), UMTS (3G) and LTE (4G). We use only the antennas which were constructed before 2017 to make sure that individuals in our survey could use these antennas. For each household we calculate distance to the closest antenna of each technology.

4.2 Statistics

We define digital finance as the use of online services and mobile apps to access financial services without the need to visit a physical bank branch in this paper. Table 1 presents information on the adoption of financial services, Internet use and smartphone adoption across the surveyed countries. The overall number of interviewed individuals in our sample is 12,735, with some variations across countries ranging from 1196 in Ghana to 1855 in Uganda. The level of bank account ownership amongst the sampled individuals

[8] There was also a pilot survey conducted a year earlier in Lesotho, which is not included in our analysis. For details on the representativeness, sampling and data collection see https://www.datafirst.uct.ac.za/dataportal/index.php/catalog/765.

[9] https://www.opencellid.org/downloads.php.

Table 2 Average distance to towers across in km

	Ghana	Kenya	Mzbq	Nigeria	Rwanda	Senegal	S. Africa	Tanzania	Uganda	Total
Tower										
GSM	4.15	1.48	10.78	3.95	2.83	1.33	1.98	8.91	5.87	4.48
UMTS	5.79	1.84	12.98	5.68	4.19	2.42	2.23	11.31	6.61	5.73
LTE	79.65	14.60	499.70	163.11	25.21	101.13	10.90	106.92	69.69	112.80

Source: Author's own calculation based on data sources explained inSect. 4.1

is 28.9% whilst 38.5% of individuals use digital financial platforms to conduct their financial transactions. In our sample, 34.8% use mobile money and 17.0% have a credit card. Using mobile money, owning a bank account and owning a credit card are not mutually exclusive.

There are substantial differences in usage of digital finance platforms and bank ownership across the surveyed countries. For instance, South Africa has the largest proportion of individuals who own a bank account (57.2%) whilst only 21.3% use digital finance applications. Kenya, the second country with largest proportion of individuals owning a bank account, has 88.1% of the surveyed individuals using digital finance apps to access financial services. The highest uptake of digital finance in Kenya is attributed to the success of mobile money in this country, with 80.5% of the Kenyan population using mobile money to send, receive and save money. In South Africa, 43.9% of the population are smartphone users and 45.7% use the Internet. The lowest smartphone penetration was in Rwanda at 10.7%. With respect to usage of mobile money, Kenya is at the top (80.5%) followed by Tanzania (55.4%). More economically developed countries, Nigeria and South Africa, have the lowest share of mobile money users, respectively 2.5% and 7.6%. As discussed earlier, this may be due to relatively high penetration of bank accounts in South Africa (57.2%). In Nigeria on the other hand, very low usage can be attributed to regulation due to which initially only banks were allowed to provide mobile money services.

Table 2 shows that there are large differences in average distance to infrastructure by individuals from different countries in our sample. We consider the following types of infrastructure. The general infrastructure is might time light intensity and towers. Coverage by mobile infrastructure is approximated by distance to antennas from different networks such as GSM, UMTS and LTE.

Table 3 compares the summary statistics for the control variables which we use in our estimation between users and non-users of digital financial technologies. The explanatory variables that we use in this study include gender, marital status, employment status, age group and income level. The statistic shows that women are less likely to own a digital account whilst married people are more likely to own a digital account than those who are not married.

In this paper, we consider individuals who live within a 2 km radius to have full coverage. The coverage by these different networks is highly correlated, where approximately 66% of individuals in our sample live within 2 km from GSM tower, 64% from UMTS tower and 21% from LTE tower. There are large differences with respect to this statistics between countries in our data. There are large differences in coverage across countries, as shown in Table 4.

Table 3 Summary statistics across by explanatory variables

	(1) Full sample	(2) Digital account	(3) No-digital account
Female	0.53 (0.499)	0.49 (0.500)	0.58 (0.493)
Married	0.50 (0.500)	0.52 (0.500)	0.48 (0.500)
HHsize	4.11 (2.448)	3.77 (2.293)	4.49 (2.554)
None	0.17 (0.374)	0.05 (0.219)	0.30 (0.457)
Employed	0.18 (0.385)	0.29 (0.455)	0.06 (0.235)
Self_employed	0.29 (0.454)	0.30 (0.459)	0.28 (0.448)
Housework	0.17 (0.377)	0.11 (0.311)	0.24 (0.428)
Student	0.12 (0.327)	0.10 (0.294)	0.15 (0.358)
Retired	0.06 (0.232)	0.05 (0.211)	0.07 (0.252)
Own_house	0.65 (0.477)	0.58 (0.494)	0.73 (0.444)
Car	0.09 (0.292)	0.14 (0.347)	0.04 (0.204)
Motorbike	0.08 (0.273)	0.09 (0.281)	0.08 (0.264)
Television	0.53 (0.499)	0.66 (0.473)	0.37 (0.484)
Bank account	0.52 (0.499)		
N	12735	6684	6051

Source: Author's own calculation based on data sources explained in Sect. 4.1

Mean coefficients; sd in parentheses; *$p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 4 Share of people within 2 km distance from antennas

Country	GSM (%)	UMTS (%)	LTE (%)
Ghana	68	71	19
Kenya	77	66	46
Mozambique	58	57	0
Nigeria	64	67	7
Rwanda	61	50	14
Senegal	83	78	12
South Africa	74	71	47
Tanzania	59	53	32
Uganda	54	58	14
Total	66	64	21

Source: Author's own calculation based on data sources explained in Sect. 4.1

5 Empirical model

We consider an empirical model which has two decision stages. The empirical model you describe is a two-stage decision process. In the first stage, individuals decide whether or not to adopt a digital device, either a mobile phone or a computer/laptop. In the second stage, those who have adopted a digital device make a decision on whether or not to use a digital financial service. Digital finance in this context implies the use of digital technologies for financial transaction. All individuals who use mobile money, online banking or mobile banking are assumed to have adopted digital financial services.

Logically, as the usage of any of these financial services is related to the decision made on whether to adopt a digital device or not, these two decisions process should be jointly modelled. To account for the interdependence between these two decisions, we estimate a selection correction model with two stages. This type of model takes into consideration the joint decision-making process and corrects for potential selection biases. In the estimation of such a model, it is important to control for factors that may influence both the decision to adopt a digital device and the decision to use digital financial services. This could include individual characteristics, socio-economic factors, access to technology, and other relevant variables. In addition, the estimation method should account for the potential endogeneity between the two stages.

In our sample, there are some individuals who do not have a digital device and cannot use any of the financial services. We take this into account by estimating Heckman's sample selection model in two stages (see Heckman (1979)). The modelling strategy is based on primary decision of consumers on whether to use digital financial technologies or not. Only at a later stage, once decided to use a digital device, a consumer will be faced with a choice of using digital financial technology or not. This would suggest refuting the use of both multinomial logit and multinomial probit for a Heckman probit to correct for sample selection. Introduced for the first time by Van de Ven and Van Praag (1981), the Heckprobit allows estimating probit models when there is suspect of sample selection bias (see also Horowitz and Savin (2001); Train (2009); Pastore (2012), for further details on probit models).

In the first stage, the Heckprobit we estimate a sample selection equation by means of a probit model. The Heckprobit assumes the existence of an underlying relationship, also called a latent equation:

$$y_i^* = \alpha X_i + \epsilon_i, \tag{1}$$

such that the binary outcome is observed, which is mirrored by a probit equation:

$$y_i = (y_i^* > 0), \tag{2}$$

where y_i^* takes value of 1 for individuals having a mobile phone and 0 otherwise and $\epsilon_i\, N(0, 1)$ is assumed to be normally distributed with mean 0. The vector of estimated parameters is denoted by $\varphi = (\alpha, \sigma_\epsilon)$. In the second stage, the modified usage equation is estimated for the sample of individuals with an account.

$$y_i = \alpha X_i + \beta Z_i + \sigma_{u\epsilon} h(X_i; \hat{\varphi}) + e_i. \tag{3}$$

In Eq. (3), we use the fact that the error term ε_i can be decomposed into the sum of two terms, $\varepsilon_i = \sigma_\epsilon \lambda(X_i, h_i; \hat{\varphi}) + e_i$, where by construction e_i is mean zero conditional on X_i. The inverse Mills ratio,[10] denoted by $\lambda(Z_i, h_i; \hat{\varphi})$, is computed using the first-stage probit estimates:

$$\lambda_i(N_i, W_i, h_i; \hat{\varphi}) = \frac{\phi(\hat{\delta} Z_i))}{\Phi(\hat{\delta} Z_i)}. \tag{4}$$

[10] The inverse Mills ratio, sometimes also called "non-selection hazard", arises in regression analysis to take account of a possible selection bias. James Heckman proposed a two-stage estimation procedure using the inverse Mills ratio to correct for the selection bias. In a first step, a regression for observing a positive outcome of the dependent variable is modelled with a probit model. The inverse Mills ratio must be generated from the estimation of a probit model. Logistic model cannot be used since the Heckam's two-stage procedures assumes normality. The estimated parameters are used to calculate the inverse Mills ratio, which is then included in the estimation of the outcome equaltion to correct for selectivity bias (Flores-Lagunes and Schnier 2012).

Heckman's selection model also needs to satisfy the exclusion restrictions. We need at least one variable which determines the adoption of digital financial services and is included in X_i, but which does not impact the adoption of mobile phones and is not correlated with the error term e_i in the usage Eq. (3). An exclusion restriction is necessary to generate credible estimates, as it requires at least one variable with a non-zero coefficient in the selection equation but not in the equation of interest. This variable serves as an instrument. When the exclusion criteria is not met, identification relies on weak functional form assumptions and the functional form may be very close to a linear functional form. This may cause multicollinearity problem in the second stage.

In the first stage we estimate the following equation:

$$\text{device}_i = \alpha X_i + \gamma_1 \text{tower}_{\text{dist}} + \epsilon_i, \tag{5}$$

where device_i takes the value of 1 for individuals owning any of the following mobile phone, computer, laptop or Internet and 0 otherwise, where X_i denotes a vector of individual and household characteristics such as gender, income, education, household access to electricity and household size. Our main variable of interest is availability of infrastructure measures by distance to tower ($\text{tower}_{\text{dist}}$), where distance to UMTS and GSM measures mobile coverage and distance to 4 G/LTE towers measures availability of Internet infrastructure. All the infrastructure variables are expected to have negative effect on financial inclusion, implying that as distance away from mobile network towers increases the probability of an individual to be financially included declines. For the second stage the modified usage equation is estimated for the sample of individuals that have a mobile phone as follows:

$$\text{DFS}_i = \alpha X_i + \gamma_1 \text{tower}_{\text{dist}} + \beta Z_i + \sigma_{u\epsilon} h(X_i; \hat{\varphi}) + e_i, \tag{6}$$

where DFS_i denote digital financial services and takes the value 1 if an individual use one of the digital financial technologies and 0 otherwise. Digital finance include all individuals who use digital technologies to conduct financial transactions such as Internet banking and mobile wallets (mobile banking and mobile money). All other variables are as per definition in Eq. (5). To identify the impact of investment on Internet infrastructure on financial inclusion, we conduct a counterfactual simulation. In the counterfactual simulation, we assume that the whole population lives within 2 km from towers of any of these networks (GSM, UMTS and 4G/LTE) and assess the impact in financial inclusion and take up of different financial services.

In the counterfactual simulation we consider two populations, one that has full coverage, the reference group, and a population that lives outside the radius of 2 km represented by $\kappa \in K = 0, 1$. It is assumed that all individuals who live within a radius of 2 km from a particular tower have full coverage in respect to the technology of the tower whilst that lives outside the 2 km radius are not covered.

6 Results

Estimation results of the effects of network coverage on financial inclusion are presented in Table 5. We estimate three heckprobit model specifications. In the first stage consumers decide whether to adopt a digital device or not. In the second stage, those who have adopted the device face a choice of deciding whether to use a digital financial platform or

Table 5 Two-stage procedure: adoption of digital financial inclusion technologies and distance to towers (stage one: adoption of digital devices)

Variables	GSM		UMTS		LTE	
	Account	Phone	Account	Phone	Account	Phone
GSM	− 0.151***	− 0.279***				
	(0.0375)	(0.0133)				
UMTS			− 0.153***	− 0.250***		
			(0.0288)	(0.0118)		
LTE					− 0.0378***	− 0.125***
					(0.0145)	(0.00898)
Female	− 0.0403	− 0.211***	− 0.0517	− 0.215***	− 0.0215	− 0.193***
	(0.0396)	(0.0271)	(0.0385)	(0.0272)	(0.0378)	(0.0269)
HHsize	− 0.0100	− 0.0149***	− 0.0106	− 0.0159***	− 0.0110	− 0.0165***
	(0.00751)	(0.00558)	(0.00750)	(0.00558)	(0.00752)	(0.00554)
Employed	0.499***	0.663***	0.521***	0.666***	0.512***	0.717***
	(0.0703)	(0.0462)	(0.0637)	(0.0462)	(0.0706)	(0.0459)
Self employed	0.163***	0.350***	0.185***	0.363***	0.157***	0.339***
	(0.0566)	(0.0338)	(0.0536)	(0.0338)	(0.0541)	(0.0334)
No education	− 0.668***	− 0.835***	− 0.719***	− 0.840***	− 0.668***	− 0.886***
	(0.112)	(0.0366)	(0.0953)	(0.0365)	(0.110)	(0.0361)
Student	0.255***	− 0.406***	0.237***	− 0.404***	0.281***	− 0.362***
	(0.0691)	(0.0420)	(0.0679)	(0.0420)	(0.0648)	(0.0417)
Retired	− 0.217**	− 0.225***	− 0.225***	− 0.217***	− 0.200**	− 0.195***
	(0.0860)	(0.0579)	(0.0849)	(0.0579)	(0.0848)	(0.0577)
Computer	0.433***		0.427***		0.457***	
	(0.0529)		(0.0531)		(0.0526)	
Assets	0.165***	0.406***	0.172***	0.398***	0.161***	0.389***
	(0.0560)	(0.0416)	(0.0530)	(0.0416)	(0.0542)	(0.0409)
Constant	0.470***	1.254***	0.457***	1.260***	0.479***	1.416***
	(0.0789)	(0.0599)	(0.0775)	(0.0598)	(0.0781)	(0.0660)
Observations	12,650	12,650	12,650	12,650	12,650	12,650

Standard errors in parentheses

***p < 0.01, **p < 0.05, *p < 0.1

not. All the decisions are denoted as 0–1 variable with a variable taking 1 if a consumer decide to adopt a digital platform and 0 otherwise. We exclude computer ownership in the first-stage estimation to meet the Heckman exclusion criteria. In Table 5, Columns 1 and 2, network coverage is measured by the Euclidean distance between a GSM tower and household whilst in Columns 3 and 4 coverage is measured by calculating the distance between a household and UMTS tower. Last, Columns 5 and 6 present results of the effect of LTE coverage on financial inclusion using distance between households and LTE tower as a measure of coverage. For robustness check, we run the model without control variables (see Table 7 in Appendix). Our results are consistent across all specifications.

After controlling for household and individual characteristics, we find a negative and significant relationship between distance to a mobile network tower and adoption of mobile phones. That is people who live in areas with mobile network coverage are more likely to own a mobile phone than those who live in households that are far away from towers. However, the results suggest that the effect of mobile network towers on adoption of mobile phone varies significantly. In terms of magnitude, the results indicate that GSM network infrastructure has a larger impact on mobile phone adoption than UMTS and LTE networks. When controlling for UMTS coverage, the effects in Model 4 decreases only slightly from 0.279 in Model 2 to 0.250. The effect of LTE coverage, presented in Model 6, is much smaller, almost half of the effect of UMTS coverage. Results obtained from the second stage suggest that individuals who live near towers are more likely to adopt digital financial platforms than those who live far away from network towers. In terms of magnitude, the results indicate that GSM and UMTS coverage has a larger impact on the adoption of digital financial platforms than LTE. To illustrate, the latter finding suggest that GSM and UMTS are the main drivers of financial inclusion especially amongst those who are generally excluded. It can also be discerned from this finding that non-based Internet digital financial services such as mobile money are the main drivers of financial inclusion in sub-Saharan African countries. These results suggest that high investment on coverage especially in rural areas is more likely to increase access to digital financial services to those who were previously excluded. That is policymakers can leverage on mobile network coverage to expand access to financial services.

The results also show that whilst there is a persistent inequality between male and female across all specification in adoption of mobile phones, there is no significant difference in the adoption of digital financial technologies. Whilst our results are consistent with existing literature in terms of inequalities in mobile ownership, our results indicate that once the mobile phone ownership hurdle has been overcome gender disparities disappears. Our results contradict the findings of Demirgüç-Kunt et al. (2013) and Zins and Weill (2016), who conclude that males are more likely to be financially included than females. However, the second-stage results indicate that individuals with no form of education are less likely to use digital financial services. On the other hand, the study shows a positive and significant relationship between digital financial services and employment, with employed individual more likely to adopt a digital financial service than those who are not employed.

The results also indicate that employment is a significant determinant of mobile phone ownership. We also obtain a positive and significant relationship between students and digital finance account ownership. We also find that wealthier individuals, measured by assert ownership, are more likely to use digital financial platforms. That is as asset ownership increases, the probability of adopting digital financial platforms increases. Our results are consistent with the notion that wealthy individuals are more likely to be financially included than the relatively poor (see for instance Von Fintel and Orthofer (2020). Our results reveals that financial inclusion inequalities are largely driven by education, income, location and employment status. Our results remain robust to different specifications.

Given other individual and household characteristics, we find no significant relationship between household size and adoption of digital financial platforms. However, the results from the first stage estimation show that individuals who live in larger households are less likely to own a mobile phone than those who live in smaller households. On the other hand, individuals who live in households that own a car or a motor bike are more likely to have a digital financial platform than those who do not own a car or motor bike. These results are a further indication of inequalities that exists in the financial inclusion space with individuals who live in poor households less likely to included. Consistent with the findings of Demirgüç-Kunt et al. (2013) and Zins and Weill (2016), our results are a further indication that digital technologies exacerbate the historical inequalities and are determined by wealth, education and employment status.

Table 6 Counterfactual simulations

Country	GSM coverage			UMTS coverage			LTE coverage		
	Base	Counterfactual	Change	Base	Counterfactual	Change	Base	Counterfactual	Change
Ghana	0.70	0.71	0.01	0.68	0.71	0.03	0.70	0.73	0.03
Nigeria	0.07	0.08	0.01	0.07	0.08	0.01	0.08	0.09	0.01
Mozambique	0.52	0.53	0.01	0.49	0.52	0.03	0.52	0.58	0.06
South Africa	0.26	0.27	0.01	0.26	0.26		0.26	0.27	0.01
Rwanda	0.66	0.68	0.02	0.64	0.67	0.03	0.67	0.70	0.03
Kenya	0.94	0.94		0.93	0.94		0.94	0.94	
Senegal	0.51	0.51		0.50	0.51	0.01	0.51	0.54	0.03
Tanzania	0.86	0.88	0.02	0.85	0.88	0.03	0.87	0.88	0.01
Uganda	0.93	0.94	0.01	0.92	0.93	0.01	0.93	0.94	0.01

Source: Author's own simulations based on the two-stage procedure results in Table 5

In Table 6, we present the results obtained from counterfactual simulations. We consider that the whole population lives within 2 km radius of these networks. We find that in such scenario the adoption of digital finance platforms would increase by 2% on average. Our results indicate that investment on LTE network would have a much larger effect on financial inclusion than GSM and UMTS. In a case where the whole population reside within a radius of 2 km from an LTE tower, financial inclusion will increase by 6% in Mozambique and 3% in Ghana, Rwanda and Senegal. However, investment in GSM and UMTS towers will only increase financial inclusion by 1–2% and 0–3%, respectively. In Tanzania, our results indicate that investment in GSM and UMTS would have a larger effect than investment in LTE towers. The varying effects on investment in coverage can be attributed to varying financial structures across these countries. For instance, in some countries such as Kenya, Tanzania and Uganda digital financial technologies are mobile network based and often run-on GSM and UMTS networks whilst in Southern African countries—South Africa and Mozambique financial technologies are bank led and often requires Internet to operate. On the other hand, the effect of network coverage in Nigeria is very minimal despite majority of Nigerian not financially excluded. This can be attributed to the disabling regulatory environment which required individuals to have a bank account to use financial technologies such as mobile money. Our results emphasise the role of investment in network coverage, especially in rural areas for improving access to services that are usually not available to the poor. To the best of our knowledge this is the first study which uses a very detailed individual-level data from a number of African countries with geo-location information that is combined with detailed geographical data on infrastructure coverage.

7 Conclusion

In this paper, we analyse how the proximity of mobile networks infrastructure impact the decision to adopt a mobile phone and to use digital financial services. We use a rich survey data of 12,735 individuals conducted in 2017 in nine sub-Saharan African countries: Ghana, Kenya, Mozambique, Nigeria, Rwanda, Senegal, South Africa, Tanzania and Uganda. We combine the survey data with detailed information on the proximity of physical infrastructure using information on geo-location of respondents. We approximate coverage using distance from the household location to mobile towers of GSM, UMTS and LTE networks.

We estimate a two-stage model, where in the first stage consumers make the decision to adopt a mobile phone. In the second stage, they decide whether to use digital financial services. We find that network coverage has a significant impact on the decision to adopt a mobile phone. Individuals who live within 2 km radius from GSM, UMTS and LTE towers are more likely to adopt a mobile phone. On the other hand, results from the second stage estimation show that UMTS and GSM coverage have a larger impact on the use of digital financial services than LTE networks.

After considering both individual and household characteristics, we find substantial gender disparities in mobile phone ownership but once the hurdle has been overcome the gender disparity in digital financial inclusion disappears. However, the study shows that even after adopting a mobile phone wealth, employment and education are the main determinants of digital financial inclusion. The results shows that the educated, wealthy and employed are more likely to be digitally financially included than the non-educated, the poor and the unemployed populations. On the other hand, the results suggests that digital financial services act as compliments to wealthy, educated and employed groups and act as a substitute to those who were previously marginalised as could not access the formal financial services. The results are further indicated that mobile money, which does not necessarily require a user to have access to Internet, is the most common driver of financial inclusion in sub-Saharan Africa.

In counterfactual simulations, we consider that the whole population live within 2 km radius from any of these networks. We find that in such scenario the adoption of digital financial services would increase by 0–6% depending on a country and network. We find that investment in LTE coverage would have a larger impact in Mozambique, Ghana, Rwanda and Senegal. On the other hand, in some countries such as Tanzania, investment in GSM and UMTS coverage would increase financial inclusion by a larger margin than LTE coverage. This outcome can be attributed to the differing financial market structure across these countries. For instance, in South Africa, Mozambique most of the financial innovation is bank led and operated on an LTE network whilst in most of East African countries financial innovations are mobile phone network led and often run within GSM and UMTS networks. Despite the differing effects, our results are an indication of the importance of investments in network coverage for reduction of financial exclusion and digital inequalities amongst African countries. To the best of our knowledge, this is the first paper which uses a very detailed individual-level data from a number of African countries with geo-location information that is combined with a detailed geographic data on infrastructure coverage.

Our results emphasise the role of investment in network coverage, especially in rural areas for improving access to services that are usually not available to the poor. To the best of our knowledge, this is the first paper which uses a very detailed individual-level data from a number of African countries with geo-location information that is combined with a detailed geographic data on infrastructure coverage. The findings can inform policy implications to promote investment in network coverage to reduce digital and financial inequalities. Whilst investments in LTE towers have a potential to reduce digital inequalities investment in UMTS and GSM towers have a potential to improve financial inclusion in underserved areas. Further work on this topic is recommended to future researchers, either using panel data to estimate the impact of investment on towers on financial inclusion and analysis of how digital financial technologies improves transactional flows between the relatively richer and the poor. Further work on this topic should also investigate how these technologies help the poor to prepare against risk.

Appendix

See Table 7.

Table 7 Two-stage procedure: adoption of digital financial inclusion technologies and distance to towers (stage one: adoption of digital devices), without control variables

Variables	GSM		UMTS		LTE	
	Account	**Phone**	**Account**	**Phone**	**Account**	**Phone**
GSM	− 0.395*** (0.0125)	− 0.386*** (0.0115)				
UMTS			− 0.352*** (0.0111)	− 0.341*** (0.0103)		
LTE					− 0.112*** (0.0316)	− 0.174*** (0.00643)
Constant	0.281*** (0.0318)	0.949*** (0.0175)	0.282*** (0.0316)	0.939*** (0.0174)	0.655*** (0.128)	1.140*** (0.0260)
Observations	12,650	12,650	12,650	12,650	12,650	12,650

Standard errors in parentheses

***p<0.01, **p<0.05, *p<0.1

Abbreviations

2G	Second generation
3G	Third generation
4G	Fourth generation
ATM	Automated teller machine
Fintech	Financial technologies
GDP	Gross domestic product
GPS	Global positioning system
GSM	Global System Mobile
ICT	Information communication technologies
LTE	Long-term evolution
PIN	Personal identification number
UMTS	Universal Mobile Telecommunication System

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Author contributions

All authors have participated in (a) conception and design, or analysis and interpretation of the data; (b) drafting the article or revising it critically for important intellectual content; and (c) approval of the final version.

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Availability of data and materials

The dataset used in this paper has been generated using various dataset, as specified in the paper. The dataset is not publicly available and can be obtained from the corresponding author on reasonable request.

Declarations

Competing interests

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