

Infrastructure Diffusion and the Use of Self-Service Banking Applications: A Micro-Spatial Approach

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Abstract

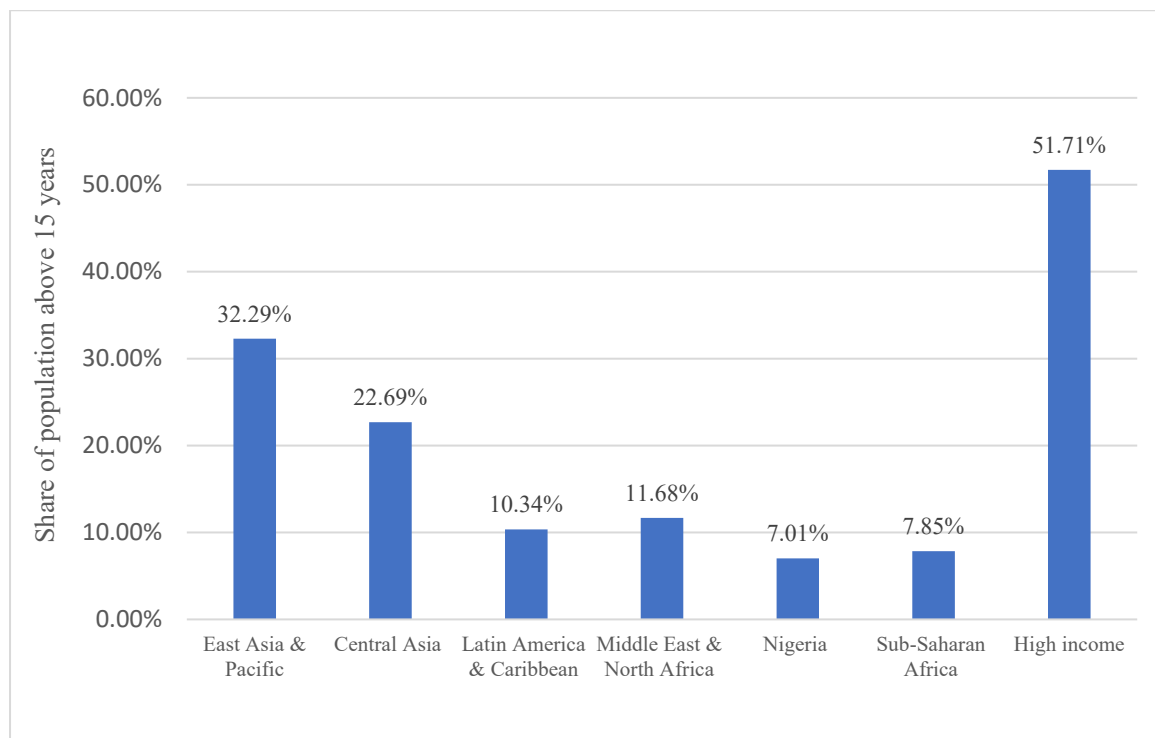
Self-service Banking Applications (i.e., internet and mobile banking) facilitate remote access to financial services by bank account holders while also offering productivity and cost savings for banks. In this study, we combine a unique dataset, constructed by matching geo-referenced cell tower infrastructure data and a nationally representative survey of 21,844 individuals in Nigeria, to investigate how infrastructure diffusion affects the use of Self-service Banking Applications (SSBAs). Our analysis is underpinned by a novel micro-spatial approach used to compute the number of cell towers within a radial specification of respondents' street-level locations. After controlling for individual and regional covariates and addressing the endogeneity issue, we find that cell tower concentration increases the probability of using mobile and internet banking, although this effect is stronger for mobile banking. Our results are robust to alternative specifications for cell tower concentration. The findings of this paper underscore the view that promoting access to financial services requires implementing policies aimed at closing the digital divide associated with the diffusion of telecom infrastructure and contemporaneous technologies like smartphone devices.

1. Introduction

Self-service banking applications (SSBAs) such as mobile and online banking provide a fundamental shift in the way service providers interact with their customers via a range of technology-driven platforms (Chiorazzo et al. 2018). These technologies have become vitally important to facilitate remote access to banking services during the present pandemic situation of COVID-19 where customers have limited access to brick-and-mortar services. From a customer viewpoint, self-service technologies enable new modes of access to services when required, thereby facilitating efficient delivery of business transactions over long distances, and reducing the time of undertaking day-to-day transactions such as paying bills, accessing savings, etc. This study, therefore, aims to bring much-needed attention to factors that influence the use of self-service applications.

Although SSBAs have gained widespread acceptance and use in developed countries, the same cannot be said of deployments in developing countries, especially those in sub-Saharan Africa (SSA). Fig. 1 presents data on the penetration of mobile and internet banking services across different development regions of the world. The 8% SSBA penetration in the SSA region is the lowest across all regions of the world, and Nigeria's figure of 7% further portrays this problem. This figure is considerably lower than the penetration levels in other developing regions of the world- 12% in the Middle East, 10% in Latin America, and 22% in Central Asia.

Figure 1: Number of users accessing bank accounts using a mobile phone or the internet.



Source: The Global Findex Database (World Bank, 2017)

However, several reports from international bodies such as the African Development Bank (AfDB, 2019) and Brookings Institute (2018) have indicated that Africa's basic infrastructures are not as strong as they should be to accommodate new technologies. Specifically, the report by the African Development Bank has suggested that African countries experience a technology gap and that an estimated \$170 billion a year is needed to achieve its true potential (AfDB, 2019). Loxley (2013) argued that only US\$45 billion (of the required annual technology needs of a total of US\$93 billion) is available, leaving a 'technology gap' of US\$48 billion. Consequently, the dearth of Information Communication and Technology (ICT) infrastructure is often argued to be the main reason for the low adoption rate of self-service technologies (SSTs) in Africa (Donovan, 2012). These technologies are crucial to facilitate the deployment of important ICTs such as SSTs. This infrastructural challenge is a far cry from the situation in more developed regions of the world where access to relevant technologies that underpin the utilization of SSBA has been available for several decades.

A closer look at the infrastructural challenges across the SSA region suggests that, even within countries, the unequal geographical distribution of ICT infrastructure¹ may be driving the digital inequalities in the usage of these new technologies. For instance, in Nigeria, the largest country and economy in SSA, we observe low SSBA penetration at 7% and a dearth of ICT infrastructure (Adenikinju et al. 2002; Economist, 2016; World Bank, 2017; Demircuc-Kunt, et al. 2020). The low penetration of these financial technologies poses a unique challenge for Nigeria where over 4% of bank branches have been permanently shut down since the beginning of the Covid-19 pandemic (KPMG, 2020; IMF, 2021). This likely acceleration in the digitalization of banking operations and services² highlights the need to better understand the relationship between IT infrastructure provision in Nigeria and SSBA. Whilst telecoms operators in Nigeria have invested massively to expand network coverage and internet connectivity during the last decade, the diffusion of digital technologies has been hampered by the geographically unequal infrastructure distribution (Forenbacher et al. 2019; Danquah and Owusu, 2021). But to what extent exactly does the geographical heterogeneity in infrastructural diffusion drive the usage of digital technologies such as SSBA?

Nigeria provides an interacting case study for exploring the above question given its low SSBA penetration despite the massive investments in its network infrastructure³. Moreover, an additional layer underpinning our choice of Nigeria is the ongoing discussion across its policy circles regarding the critical role of ICT infrastructure in driving the financial digitalization agenda. For example, the Central Bank of Nigeria (CBN) emphasizes the pertinent role of infrastructure diffusion in driving the adoption of branchless banking technologies (CBN 2015, p3). To this end, the Nigerian Communications Commission (NCC) sets out the development of a solid ICT infrastructure as the central pillar of its current digital strategy (NCC, 2020, pp.9-11). Hence, Nigeria provides an interesting economic, geographical, and policy context to investigate the extent to which ICT infrastructure diffusion shapes SSBA usage.

¹ A spatial exploration of 3&4G telecoms infrastructure across Nigeria indicates geographical heterogeneity in their distribution. See https://www.mobilecoveragemaps.com/map_ng#6/11.049/7.460

² <https://african.business/2020/11/finance-services/banks-accelerating-digitisation-in-wake-of-covid-19/>

³ According to the NCC, the Nigerian telecoms sector recorded investments of over \$68 Billion from 2001 to 2019 (NCC, 2020, p. 15)

Another major contribution of our study relates to how we address or capture the role of geographical heterogeneity in the distribution of ICT infrastructure in shaping SSBA usage across Nigeria. To address this, we construct a microgeographic measure of ICT infrastructure diffusion at the 5km-grid level for each household in our data sample. Using geocoordinates of over 20,000 respondents across Nigeria, we examine the extent to which the infrastructure effect varies. To the best of our knowledge, this nationally representative survey data is by far and away one of the largest technology surveys ever used to analyze technology diffusion and usage in sub-Saharan Africa. This confers three specific benefits which we detail as follows. First, the survey collects granular geo-location information that allows us to create a unique dataset by matching respondents' residences to geo-referenced cell tower information. Thus, our technology diffusion measure is based on the concentration of cell sites at the street-level for each respondent. This micro-spatial approach provides valuable information on the heterogeneity of individual-level infrastructure access. Second, the survey is a nationally representative survey that covers all geographical regions across Nigeria. More specifically, the survey covers around four towns/cities within each state in Nigeria, providing the possibility to extract a dataset that is geographically and culturally representative. Hence, beyond geographical heterogeneity, the dataset allows us to examine how the infrastructure-technology usage relationship varies across cultural boundaries. Even within a single country, the within-country variation in cultural boundaries is known to play a crucial role in shaping the distribution of ICT infrastructure, especially in the African context (see, e.g., Hodler and Raschky, 2017). Third, beyond eliciting information on the usage of financial technologies, the survey also includes the social and economic conditions of households. Consequently, we derive a comprehensive dataset spanning aspects required to estimate the infrastructure-technology usage nexus while controlling for a range of household-level and regional-level covariates.

The third contribution of this study pertains to our examination of the role of transaction costs and functional regulation: two important issues that shape SSBA usage but have hitherto not been explored in the Nigerian context. Specifically, we explore how two countervailing transaction costs affect SSBA usage. The first pertains to the cost of SSBA usage and it is expected that higher user subscription cost limit the use of SSBAs. The second transaction cost is associated with the inconvenience imposed by the geographic distance to brick-and-mortar bank branches which will plausibly increase the incentives to use SSBAs such as to overcome distance barriers to accessing banking services⁴. Studying how these countervailing considerations shape SSBA usage presents an interesting but hitherto unexplored issue in the received literature. Furthermore, SSBAs constitute technologies that operate at the delicate intersection between telecommunications and banking- whilst banks often develop these technologies, they require backbone platforms provided by telecommunication operators. Hence, in practice, tensions and conflict can arise between banks and network operators, regarding the delivery and share of business relating to financial technologies. This complex regulatory interface, which has been highlighted in the literature (Porteous, 2006; Davidson, 2011; Klein and Mayer, 2011), has become a

⁴ This geographic distance barrier is particularly relevant to the SSA region. See https://www.theglobaleconomy.com/rankings/bank_branches/

hot-button issue in Nigeria⁵. Yet the effect of this functional regulation issue on SSBA usage has not been empirically examined. We fill this gap in this study.

Our study is related to the stream of research that has looked at the role of new infrastructure technology (and its diffusion) to support the expansion of banks' branch networks. A common theme in this literature is that technology increases banks' geographic distance. For instance, Berger and DeYoung (2006) show that technological progress has promoted banks' geographic expansion further away from parent branches to remote locations. The benefit of such geographic expansion is portrayed in Petersen and Rajan (2002) who find evidence of technology facilitating small business lending to increasingly distant customers. More recent work by D'Andrea and Limodio (2020) also shows that technology diffusion (that is, the introduction of high-speed internet) promoted private-sector lending by banks, and credit and sales firms. Considering these studies, our examination of how mobile infrastructure diffusion influences the use of SSBA offers new insight into how technology may promote banks' geographic presence via branchless banking services.

2. Research Issue

There is evidence to show inequalities in access to financial services have continued to grow. Specifically, the legislation and infrastructure facilitating access to financial services remain a challenge in most African countries (McKinsey, 2011). According to recent data, close to one-third (1.7 billion) of adults remain unbanked (Demirgüç-Kunt & Klapper, 2012). This problem is prominent in sub-Saharan Africa (SSA), which also serves as the empirical context of this study. It is characterized by lower penetration rates for mobile and internet banking compared to other regions of the world (World Bank, 2017). The study is thus motivated by the high levels of financial exclusion, and poor financial development in the SSA region.

Furthermore, the challenge of financial inclusion mainly affects certain groups. About half of the unbanked people include women in poor households, those living in rural areas, or people out of the workforce (Demirgüç-Kunt & Klapper, 2012). Ghosh and Vinod (2017) found that female-headed households are 8% less likely to access financial services compared to households that males head. The limited attention of previous literature to the African context may explain why financial inclusion remains a significant challenge for many countries within the continent. Policy prescriptions should be made with the consideration of how cultural, economic, and other contextual variables influence the validity of orthodox approaches to financial inclusion in SSA. Yet, robust empirical evidence and re-examination of the relevant theories to inform financial inclusion policy germane to the African context are few and far between. Financial inclusion research in the African context is necessary and should be of particular interest to both academics and policymakers to expand our understanding and facilitate broader development outcomes. Consequently, empirical studies based on developing countries are needed to provide insights that inform the broader understanding of the use of SSBA. Given the above arguments, this study steers clear of the extant literature by investigating the effect of infrastructure

⁵ <https://www.bloomberg.com/news/articles/2021-04-20/late-to-fintech-boom-nigerian-banks-turn-to-regulators-for-help> and <https://guardian.ng/news/telecoms-operators-withdraw-ussd-service-from-banks-over-n42b-debt/>

diffusion and other usage predictors on two major SSBA (internet and mobile banking) in the context of SSA country.

Given that geographic disparities in technology access are significant to addressing these financial development issues, this study makes an important contribution to our empirical understanding of this technology-finance nexus, by offering valuable insight into the effect of variation in technology access on the usage of SSBA in a developing country context. This is especially important for rural geographical areas where these network technologies often represent the foremost modern technology of any kind (Aker and Mbiti, 2010). Unless the type of analysis here is undertaken, it may be impossible to untangle the role of geographic disparities in technology access on the usage of these SSBA, such that these disparities may be incorrectly explained away as differences across individual income or demographic characteristics.

3. Research Objectives

In this paper, we are interested in providing answers to the following research objectives:

- a. How does infrastructure diffusion influence the usage of SSBA, as measured by mobile banking and online banking usage?
- b. How do transaction costs influence the usage of SSBA?

To answer the research objectives outlined above, we consider Nigeria, a developing country in the SSA region, as a case study. Why? Given that the country accounts for the largest proportion (18%) of the entire SSA region (World Bank, 2020), it offers a useful case study for addressing our research question. For instance, as we show later in the data section that the average network infrastructure concentration in Nigeria is broadly consistent with the levels observed across broader African regions. Furthermore, the similarly low penetration of SSBA in Nigeria and the SSA region provides some indication that Nigeria can offer some useful insight into the technology diffusion-SSBA relationship in the sub-Saharan African context. Domestically, other important considerations that make the Nigerian case interesting are worth highlighting. For example, ITU estimates indicate that more than 90% of the youth population in developed countries use the internet compared to 30% in less developed regions of the world. Considering that the proportion of Nigeria's population below 40 years is projected to reach 81% by 2030, broadband penetration is likely to have a significant role in shaping Nigeria's participation in an increasingly digitalized future economy. Also, despite growing to become Africa's largest economy and one of the major developing countries in the world, Nigeria epitomizes the co-existing low level of internet penetration and ICT infrastructure deficit (Economist, 2016).

4. Background and Conceptual Framework

There is robust evidence in the literature that the internet provides opportunities for banks to decrease their reliance on physical branches and move services online, thereby allowing banks reduce to costs and serve customers and markets they otherwise could not reach. Hernando and Nieto (2007) estimate the impact of internet banking adoption over 70 Spanish banks from 1994 to 2002 and find that the adoption of internet banking as a delivery channel of financial services leads to a reduction in a bank's overhead expenses. Using a panel data that comprises 105 banks, which represent over 80% of the banking assets of the Italian banking organization during the entire 1993-2002 period, Ciciretti et al.

(2008) provide a strong, significant association between the adoption of Internet banking by traditional banks and their profitability. Onay and Ozsoz (2013) provide robust evidence using a panel of 18 retail banks in Turkey, that Internet banking adoption has a positive impact on the level of profits, deposits, and loans per branch from 1990 to 2008. Arnold and van Ewijk (2011) study Pure-play internet (PPI) banks - the scenario where a bank establishes a virtual branch where financial services are delivered via online and mobile channels. While PPI banks offer greater scalability, Arnold and van Ewijk (2011) find that PPI banks may also generate overexposure in risky markets.

Regarding why banks choose to adopt web-based financial services, Dandapani et al. (2018) find evidence that adopting web-based services, such as online banking, is consistent with the profit-maximization behaviours of financial providers. Hernández-Murillo et al. (2010) find that bank-specific characteristics, such as standard measures of financial health and bank size, are the main determinants in the adoption decision. Looking at behavioral triggers, Hernández-Murillo et al. (2010) also find that banks adopt online banking services earlier in markets where their competitors have already adopted this technology and that larger banks (that is, banks in multigroup holdings) are likely to adopt earlier. This finding is also supported by Ciciretti et al. (2008) who also found that larger banks (that is, national and inter-regional Italian banks) were most active in Internet banking activities.

4.1 The role of infrastructure diffusion on SSBAs

A salient observation from the literature concerns the overwhelming focus on more developed countries of the world (e.g., Czernich et al. 2021). Of those that have been conducted in developing countries, studies investigating the African context are far more limited in the literature. Despite the potential benefits of investments in SSBAs, the unique challenge of inadequate technological infrastructure still stalls its implementation in African countries such as Nigeria. Hence, more studies are needed to provide a richer understanding of what drives SSTs in African countries where factors such as income and technological infrastructure are relatively inadequate compared to other developed countries of the world. Compared to other low and middle-income countries in the other parts of the world, African countries generally lag when it comes to access to key technology such as ICT, power, transport, etc. (Loxley, 2013). The use of technologies such as banking SSTs and their associated benefits may well be critical to uplifting the economies of less developed and developing countries especially those in Africa (Neto et al. 2005). Mobile infrastructure is an important technology in expanding the provision of financial services to the unbanked population (Assunção, 2013). Thus, the use of SSBAs such as internet and mobile banking services is likely to be influenced by the availability of underlying technology infrastructure.

H1a: Infrastructure diffusion will positively influence the use of mobile banking services.

H1b: Infrastructure diffusion will positively influence the use of internet banking services.

Transaction cost theory provides an additional theoretical foundation for the conceptual model of this study. In the next section, we discuss our arguments and develop the hypothesis to be tested.

4.2 Transaction costs and the use of SSBAs

Transaction cost theory by Coase (1937) has been used to explain how the cost to perform a transaction shapes the adoption of technologies (Williamson, 1988). As such, transaction cost theory is appropriate

for explaining why consumers are willing to adopt alternative channels to conduct banking transactions rather than continuing to rely on access to physical bank locations. Central to transaction cost theory is the notion that consumers will conduct transactions in a manner that minimises their transaction cost. In particular, when considering financial technologies, adoption and usage costs are important determinants of household adoption decisions (Attanasio et al., 2002; Bachas et al., 2021). Mulligan and Sala-i-Martin (2000) show that these usage costs are negatively related to financial innovation usage. Yet, beyond the costs arising from user subscription cost, an additional but different transaction cost is that relating to product convenience. Schuh and Stavins (2010) show that the most important determinants of payment platforms embody an interesting trade-off between convenience and user cost. In this light, previous research highlights how financial technologies deliver convenience by overcoming distance and its allied informational barriers. For instance, Jack and Suri (2014) show that mobile financial technologies allow users to transfer funds using simple short messaging service (SMS) technologies in a way that dramatically reduces the cost of money transfers over long distances. In this context, while lowering the transaction cost associated with transactions will likely influence the adoption and use of remote banking services, there is the additional consideration of the actual user cost of the technology. Thus, there is an interesting countervailing trade-off within the transaction cost elements facing users. For instance, while these remote technologies may reduce the costs (e.g., transportation costs) related to a financial transaction by allowing the completion of such transactions quickly in a manner that overcomes distance barriers (Aker, 2010), users will rationally require that such cost savings are greater than the monetary user cost or charge (e.g., subscription costs) of operating the technology (Jack and Suri, 2014). In this study, we examine this interesting issue by capturing these two key transaction cost dimensions: subscription costs and distance to the closest physical bank branch, extending the analysis of their impact into the presence of SSBAs.

H2a: Higher mobile subscription costs will reduce the likelihood of SSBAs

The costs associated with using mobile or online banking services such as broadband subscription costs can influence the usage of SSBAs. Consumers also need to purchase a Subscriber Identity Module (SIM) card which in turn allows them to purchase relevant broadband subscription plans used to access internet services. Assuming lower mobile subscription costs, the individual is likely to contemplate the use of SSBAs in more favourable terms, thereby facilitating usage. If the fees charged by the mobile providers are too high, individuals may refrain from the use of SSBAs. Thus, higher transaction costs can hinder the use of SSBAs leading to limited access to financial services.

H2b: Limited access to physical bank branches will increase the likelihood of using SSBAs

Proximity to physical bank branches represents a significant transaction cost that is also likely to influence the usage of SSBAs. Different from individuals who access banking services at physical bank locations, SSBA users can use a mobile phone that is connected to the internet. Online and mobile banking enables new modes of access to services when required, thereby facilitating the efficient delivery of business transactions over long distances, and reducing the time of undertaking day-to-day transactions such as paying bills, accessing savings, etc. Therefore, consumers can complete financial transactions without a physical bank branch. Hence, greater distance to bank branches embodies greater transaction costs associated with accessing financial services. This will likely foster the use of SSBAs.

4.3 Functional regulation and the use of SSBAs

Remote banking services require a backbone technology provided by telecommunication operators. Thus, one could argue that the deployment of remote banking technologies requires a partnership between banks and network operators (McKinsey, 2018). Thus, in practice, tensions and conflict can arise between banks and network operators, regarding the delivery and share of business relating to these financial technologies (Davidson, 2011). This also raises the important issue of the regulatory authorities (i.e., banking or telecoms regulators) best positioned to adequately regulate these technology platforms (Ibid). For instance, while the underlying banking and financial activities fall within the oversight of financial regulators (Weber and Darbellay, 2010), the distribution of network infrastructure is guided by regulation in the telecoms industry (Buys et al., 2009). Moreover, some regulators may require formal partnerships or arrangements between banks and mobile operators regarding such remote technologies (Aron, 2018). Thus, the above issues typify a classic challenge of functional regulation where it is difficult to distinguish which activities come under the authority of a particular regulator (Herring and Santomero, 1990; Barth et al. 2000). We investigate this question in our study context by examining the extent to which potential tensions between banking and telecommunication regulations may impact the use of SSBAs. Specifically, we explore the cross-functional effect of telecommunications regulation on the use of SSBAs:

H3: Stringent telecommunications regulation will limit the likelihood of using SSBAs.

5. Methodology

5.1 Base Model specification

In this study, our hypotheses suggest that (i) the diffusion of network infrastructure will foster the use of remote banking services (ii) the use of such remote technologies depend on their related transaction costs, and (iii) tensions between the regulatory spheres (banking and telecommunications) of network infrastructure will likely shape the diffusion of network infrastructure and usage pattern of the remote banking technologies. Thus, while (i) derives from the theoretical consensus that the diffusion of new infrastructure technology will likely support the expansion of banks' businesses to remote locations via branchless platforms (Petersen and Rajan, 2002; Berger and DeYoung, 2006; D'Andrea and Limodio, 2020). (ii) and (iii) serve as both direct influences and moderating channels for the impact of network technology diffusion on remote service use.

Theoretically, considerations about the countervailing forces between the user cost of remote technologies versus the associated costs of financial transactions will affect the usage decision of remote technologies (see Aker, 2010; Jack and Suri, 2014; Tadesse and Bahiigwa, 2015; Aker and Fafchamps, 2015). Finally, the functional regulation issues in (iii) are particularly relevant to Nigeria, where the tensions between mobile operators and banks are well-documented.⁶ To gauge the relationship between

⁶<https://www.bloomberg.com/news/articles/2021-04-08/nigerian-banks-deny-owing-mtn-nigeria-and-other-telcos>
<https://www.economist.com/finance-and-economics/2019/05/09/mobile-money-comes-to-nigeria>
<https://www.premiumtimesng.com/news/top-news/448669-nigeria-telcos-to-block-millions-from-mobile-banking-over-banks-debt.html>

network infrastructure diffusion and SSBA, and how this relationship is mediated by transaction costs and regulatory tensions, we employ the following cross-sectional Probit model:

$$SSBA_{ij} = \alpha_j + \beta diffusion_{ij} + \gamma X_{ij} + \mu Z_{ij} + \varepsilon_{ij} \quad [1]$$

where individuals and localities are indexed by i and j , respectively, $SSBA_{ij}$ is a dummy indicator variable for the use of mobile and internet banking services. The locality effects α_j ensure that we only exploit variation in $SSBA_{ij}$ based on the differences across individuals, rather than across localities. $diffusion_{ij}$ is the micro-spatial measure of infrastructure diffusion, computed as the total number of cell towers within 5km of the radius of each respondent's location at the street-level. This five-kilometer specification is premised on the fact that network coverage in SSA is mainly based on base stations that can provide service to a 5-10 kilometer radius (Aker and Mbiti 2010, p. 209).

The coefficient of interest, β , measures the association between $SSBA_{ij}$ and $diffusion_{ij}$. To ensure that β indeed captures the impact of mobile technology, rather than other contemporaneous characteristics, we include a vector of controls, X_{ij} , whose parameters are given by the vector γ . ε_{ij} is the error term. To test our hypothesis on transaction cost and functional regulation, we include an additional vector Z_{ij} which contains two dimensions of transaction cost (i.e., distance to bank branch of survey respondents and telecoms user subscription cost) and functional regulation (i.e., state-level network licensing fees). Distance to bank branch provides an implicit measure of the distance and transport cost which will likely stimulate SSBA. The distance data is collected from the survey which poses questions to respondents about the distance to the nearest physical bank branch (in minutes)⁷. The second dimension relates to the SMS and broadband/data user subscription cost, derived from the fees schedule of telecoms operators in Nigeria. We collect these user subscription cost data by identifying the telecoms operator for each respondent from the survey. For functional regulation, we capture this using the state licensing schedule available from the Nigerian Communications Commission (NCC). However, we note that whilst the licenses fee variable acts as state-level regulatory constraints on the expansion of network infrastructure across Nigeria, it is an imperfect measure of regulation that may embody indirect effects on usage via the cell towers.

The control variables in X_{ij} include demographic, socio-economic, and geographical variables in line with existing literature on the usage of banking services and ICT (e.g., Fujiki and Tanaka, 2014; Allen, et al. 2016). These variables are derived from the market survey data. We control for income because households with higher disposable incomes are more likely to be technology users compared to households with lower disposable incomes (e.g., Ajefu and Ogebe, 2019). As such, we expect income to have a positive impact on SSBA. Following previous studies (Allen et al., 2016; Hübler and Hartje, 2016), we define a binary income variable that takes the value of '1' when household income is greater than the sample average and '0' otherwise. We also include a gender variable as an additional control variable given the patriarchal nature of the study context. In such systems, the preferences and decisions

⁷ One may highlight a limitation with the distance measure since many users in the SSA or Nigerian context may not drive to their bank branches. Nevertheless, since our focus is not on the social driving status of respondents, the distance data offers a reasonable approximation to the physical distance to banks in a consistent way across the survey.

of men tend to be more dominant than those of their spouse(s) (see Bulte et al., 2016; Majlesi, 2016). Similar considerations can be extended to the marital status of an individual on the usage of ICT services. Moreover, we include the age of respondents given that, although younger individuals may have lower levels of income, they tend to exhibit greater levels of technological affinity (Bauer and Hein, 2006; Hübler and Hartje, 2016). Further, the level of education is also likely to stimulate the adoption of technology in various contexts (Karimu et al. 2016). Also, technology adoption decisions are often shaped by religious reasons, as some religious beliefs may restrict the adoption of conventional banking or technological products (Fungáčová, et al., 2019). Hence, we control for the religion of survey respondents by including a Christianity dummy variable. Finally, we control for the employment status and regional conditions of each household. Thus, the unemployment dummy allows us to capture how the effects of macroeconomic shocks on economic wellbeing, which is known to shape the adoption of technologies (Allen et al., 2016). The urban dummy ensures that we can capture the reality that the regional economic and social conditions affect adoption decisions since digital technologies tend to spread more quickly across urban clusters (Aker, 2010).

5.2 Instrumental Variables (IV) analysis

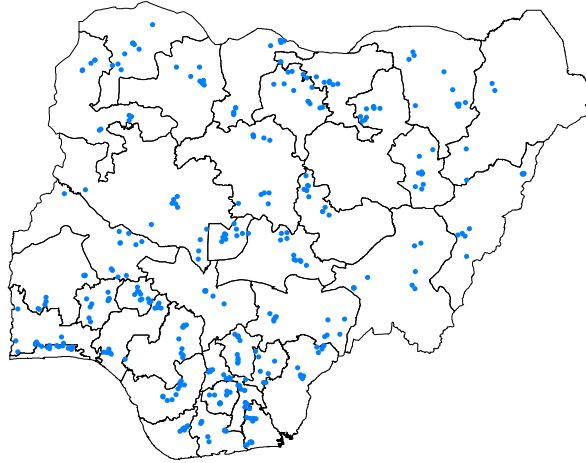
Equation [1] is plausibly susceptible to the bias arising from the endogeneity of cell tower locations within the model specification. First, network operators will likely locate cell towers in certain regions, based on market viability (e.g., population size) and geographic considerations (e.g., proximity to cities) (Buys et al., 2009). Second, there is a broader issue of the potential reverse causality arising from whether the use of SSBA improves network deployment to certain areas. In this case, SSBA usage may drive the deployment of infrastructure as part of a national policy priority to foster remote service access. Therefore, we employ topography variables (landforms, i.e., water as a fraction of land cover and ground elevation) as instruments for the infrastructure variable. Both instruments are exogenously determined by nature. Moreover, they do not directly affect individual-level SSBA usage decisions, except through their impact on $diffusion_{ij}$.

The identifying assumption is that both topographical instruments strongly influence the location of the tower infrastructure by telecommunication operators (Buys et al., 2009). For instance, a landform dominated by larger waterbodies invariably implies less land surface or physical structures for mounting towers. Moreover, cell towers and masts are physical structures designed to support radio antennas at heights that maximise the operator's ability to send or receive radio waves. Thus, the ground elevation of an area provides a natural cost-side consideration for operators aiming to attain optimal radio signals. We collect data on landforms from the Global Land Cover dataset while the ground elevation information is available from NASA's Shuttle Radar Topography Mission (SRTM) data sets. Finally, we also include a measure of pre-sample ancillary infrastructure as an instrument. The argument is that mobile networks rely on the locational maintenance cost, such that the likelihood of placing a cell tower in an area depends on the associated cost considerations. Thus, we include a measure of electricity (i.e., nighttime light intensity), obtained from the National Oceanic and Atmospheric Administration, as an instrument for local cell tower concentration. As mobile telephone networks arrived in Nigeria around 2001, we use the nightlight data for 1999 as an instrument. This ensures that the instrument is pre-determined and properly excluded from the second-stage regression.

5.3 Data Sources

We draw on two data resources to construct our database. The first is novel data from a nationally representative market survey of Nigeria, carried out by Africa’s largest mobile operator, MTN⁸ in April-July 2018. The market survey covers 21844 individuals across 730 localities (i.e., villages or towns). Figure 2 plots the GPS coordinates of the centroid of survey areas at the municipality level. The geographical spread of the surveyed areas confirms the nationally-representative nature of the survey. Our second data resource is the OpenCellID database (<http://opencellid.org>), which contains information on our main independent variable. The data contains raw information on the geolocation (longitude and latitude) of around seven million unique cell sites across the world (Hodler and Raschky, 2017). See the appendix for descriptive statistics of the dataset in this study.

Figure 2: Nigerian map showing surveyed areas.



5.4 Defining variables

Our dependent variable SSBA pertains to the use of mobile and internet banking services. To test our study hypotheses, we augment the baseline model in equation [1] to test for each of the banking applications. In other words, we include MOB_{ij} and INT_{ij} to represent the use of mobile and internet banking services, respectively. The revised equations are shown below:

$$MOB_{ij} = \alpha_j + \beta diffusion_{ij} + \gamma X_{ij} + \mu Z_{ij} + \varepsilon_{ij} \quad [1a]$$

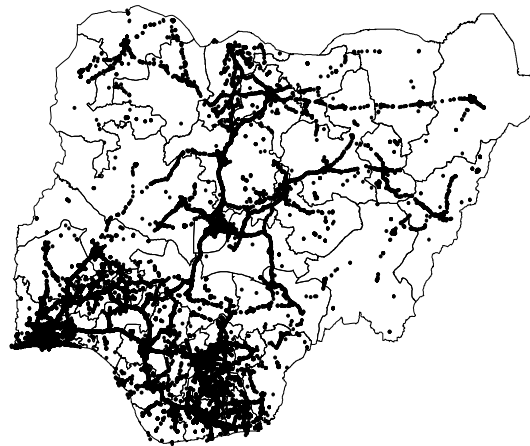
$$INT_{ij} = \alpha_j + \beta diffusion_{ij} + \gamma X_{ij} + \mu Z_{ij} + \varepsilon_{ij} \quad [1b]$$

Both MOB_{ij} and INT_{ij} variables are represented by dummy indicator variables for the use of mobile banking or internet banking services by an individual “i” in “j” locality. To construct these indicator variables, we convert survey responses on the subscription and frequency of use for both SSBA into indicator variables. Specifically, we use the question: “Which of the following activities do you access?”. Beyond mere subscription, we are interested in the frequency of use, hence, we use the

⁸ <https://www.mtn.com/> MTN is the largest telecoms operator in Africa, and it is also the market leader in the Nigerian telecoms industry, accounting for 40% market share. See statutory regulatory data. <https://www.ncc.gov.ng/stakeholder/statistics-reports/industry-overview>

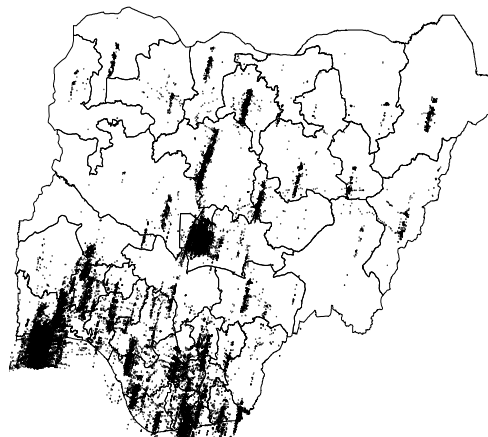
information provided in the follow-up question: “*How often do you use the service?*”. We then calculate the dependent indicator variables as dummies that take the value 1 if the SSBAs are used at least monthly⁹. Our main independent variable is a measure of infrastructure prevalence at the individual-level. We calculate this variable using information from our two data sources in four steps. First, we follow existing studies (Hodler and Raschky, 2017; Ackermann et al., 2021) by extracting and mapping the cell tower locations from OpenCellID (see Figures 3 & 4). Secondly, we extract and map respondents’ street-level locations from the survey data¹⁰. Thirdly, we overlay the cell tower map with the location map. Finally, we compute a micro-spatial mobile infrastructure variable as the total number of cell towers within a 5km-sq radius of each respondent.

Figure 3: Mobile cell towers sites in Nigeria



Source: OpenCellID data

Figure 4: Wireless internet (3G and 4G) tower sites in Nigeria



Source: OpenCellID data

⁹ The monthly usage is the most relevant frequency of use. From our total sample of 21844, around 1485 of the respondents use these services monthly relative to around 20099 who don’t use the services at all, and 260 who have access but don’t use the service monthly. The usage frequency is a design feature of the survey which the authors are unable to vary.

¹⁰ The survey provides GPS coordinates of the addresses (residence or workplace) where respondents mostly use the SSTs.

5.5 Descriptive statistics

Our data sample contains information on 21844 household observations, dwelling in 730 localities¹¹ across Nigeria. Table 1 reports the descriptive statistics for the variables in the data sample. The mean value for the mobile and internet banking SSBAs are 0.068 and 0.041, respectively. These figures, which suggest penetration rates of around 7% and 4% respectively, are within the same ballpark as the figures available from the Global Findex database which estimates the penetration of both SSBA penetration in Nigeria at 7% (Demirguc-Kunt, et al. 2020). This low penetration also seems to align with the broader SSA penetration levels as shown in Figure 1 in the study introduction. Moreover, previous SSA studies on digital financial technologies (e.g., Adegbite and Machethe, 2020; Qiu, 2022) also observe similar levels of penetration in SSBA technologies, implying that standard binary regression models are sufficient to handle such ‘sparse outcomes’ data since they reflect the reality that only a small fraction of possible SSBA adoptions are eventually made. Furthermore, in such cases, the main problem mainly arises from having a small number of adoption outcomes, rather than a small fraction. So, the order of magnitude of our penetration of 7% in a sample of over 20,000 households is not a major problem in our data set¹². Turning now to our key independent variable, the infrastructure diffusion variable at 5km, we observe that the mean value of 0.056, along with a standard deviation of around 0.08 suggests a high degree of variation in ICT infrastructure that is consistent with geographic dispersion depicted in Figures 3 and 4. The average infrastructure concentration and their geographic variability also seem consistent with the levels found across the African continent, as shown by Hodler and Raschky (2017). The importance of exploring a robustness check that squeezes the radial specification on the infrastructure diffusion variable becomes evident from the sizable differences between the diffusion measure at the 2.5km radius (0.019) and the 10km radius (0.143). These values provide an additional source of cross-sectional variation that allows us to explore the role of infrastructure diffusion on SSBA usage.

¹¹ A locality is either a city or town in Nigeria.

¹² See Belloni et al. (2019) and Graham (2020) for some treatment of the modelling challenges in sparse outcome datasets.

Table 1. Summary statistics ($N = 21844$)

Variable	Definitions	Mean	Std Dev.	Min.	Max.
Network diffusion_5km	Number of cell towers within 5 km of respondent	0.056	0.080	0	0.778
Network diffusion_2.5km	Number of cell towers within 2.5 km of respondent	0.019	0.024	0	0.384
Network diffusion_10km	Number of cell towers within 10 km of respondent	0.143	0.337	0	2.844
Mobile banking	Dummy = 1 if individual uses mobile banking service	0.068	0.251	0	1
Internet banking	Dummy = 1 if individual uses internet banking service	0.041	0.198	0	1
Income dummy	Dummy = 1 if individual's income is higher than sample average	0.325	0.468	0	1
Age	Age of the individual in years	43.974	18.394	23	75
Education	Years of formal education	13.314	4.978	0	20
Male	Dummy = 1 if individual's gender is male	0.561	0.496	0	1
Married	Dummy = 1 if individual is married	0.624	0.484	0	1
Unemployed	Dummy = 1 if individual is unemployed	0.118	0.323	0	1
Christian	Dummy = 1 if individual's religion is Christianity	0.619	0.486	0	1
Urban	Dummy = 1 if locality is in an urban area	0.508	0.495	0	1
User subscription cost	Telecommunications operator charges for mobile and internet use	82.28	14.37	62.42	126.39
Regulation	Regional license fee (LCY: Naira)	785488	611068.5	300000	3000000
Smartphone ownership	Dummy = 1 if individual owns a smartphone	0.218	0.413	0	1
Conflict	Number of conflict fatalities at the locality level	75.54	162.44	0	802
Local service quality	Regional Dropped Call Rate (DCR) (%)	32.96	22.71	12.41	59.66
Distance2Bank	How many minutes' drive is it from your house to the bank	17.519	27.668	0	270
Landform	Water as fraction of surface area (%)	2.105	1.142	0	46.961
Topography	Ground elevation (feet)	190.90	308.94	10.01	1583.58
Population density	Population of locality divided by area size in sq-km	1984.23	5801.71	26.18	58039.68
Road infrastructure	Total road length in km	77.18	104.35	0	517.09

6. Results

6.1 Baseline Results

To understand the relationship between technology diffusion and SSBA, we begin our empirical analysis by first implementing Probit regressions in Table 2. Our key independent variable of interest is the technology diffusion measure, which we compute within a 5-km radius of each sampled respondent. We winsorise the continuous control variables at the 1st and 99th percentiles to limit the effect of outliers on the model results (Angrist and Kruger, 1999; Campbell et al., 2011). Where appropriate, we further use the log transformation of some variables to check on the digital size and to reduce the remaining skewness in the winsorised dataset. Table 2 presents the average marginal effects from the baseline regression estimates, where the first 3 columns pertain to mobile banking while columns 4-6 contain the internet banking results. For both SSBA (i.e., columns 1 and 4), we start with a pooled Probit model without any control variables or locality effects. In both cases, we find that the diffusion of cell towers has a positive and statistically significant effect on the use of mobile and internet banking.

In columns 2 and 5, we add the individual and locality-level control variables. The marginal effect of the technology diffusion variable drops by around half (threefold) in the mobile (internet) regression but remains positive and statistically significant at the 1%-level. This implies that the relationship between technology diffusion and usage decisions regarding SSBA is likely not driven by other contemporaneous individual or regional characteristics. In columns 3 and 6, we add locality random effects to capture the differences across localities. The technology coefficient remains qualitatively stable across both SSBA while also retaining the positive sign and statistical significance. Interestingly, the marginal effects on the diffusion variable indicate that a 1% increase in cell tower concentration within a 5-km radius of a respondent, increases the probability of mobile and internet banking applications by 0.010 and 0.003, respectively. By implication, the magnitude of the coefficients indicates that mobile applications are relatively more responsive to the cell tower variable, underscoring its greater penetration than internet banking, as shown in the descriptive statistics table.

Turning to our other hypotheses on transaction costs, we find that the two dimensions of transactions (distance to bank branches and user subscription cost) play a significant role in shaping usage decisions. First, the distance to bank variable, an implicit transaction cost denoting distance barriers and inconvenience, is positive and statistically significant at the 1% level for both applications. This finding suggests that greater distances to respondents' physical bank branches increased the probability of usage by similar orders of magnitude relative to the technology variable. In essence, respondents employ these applications to overcome the barriers arising from travelling long distances to physical bank branches. Indeed, it appears that transaction costs and technology diffusion exhibit substitutability in the usage decisions across both applications. For the second transaction cost dimension, we find a negative and statistically significant effect on services charges, implying that higher subscription costs for using SSBA reduce the probability of usage. Besides the strong statistical significance, this cost effect is economically significant given the magnitude of the marginal effects, which we estimated at 0.189 and 0.054 for mobile and internet banking, respectively.

Furthermore, the hypothesis on functional regulation seeks to explore how the underlying telecoms regulation interferes with the two SSBA, technologies that are fundamentally designed, owned, and operated by banks. The marginal effect of the telecoms' licensing regulation is negative in the mobile model, although it loses statistical significance when we account for unobservable regional effects. Interestingly, the marginal effect of the licensing regulation is positive and statistically significant at the 1% level in the internet regression, even after controlling for regional effects. We conjecture that this finding possibly reflects the lower penetration of internet banking, along with the regional disparities in the spectrum licensing fees charged by the Nigerian Communications Commission (NCC). Under its licensing programme, state regions with higher per capita income and populations tend to attract higher regulatory fees, such that those fees are positively correlated with the probability of internet usage. In this case, states with lower underlying demand for internet or internet banking (i.e., due to lower income levels) are likely to have lower regulatory constraints in terms of deploying their services. This approach also seems consistent with the digital inclusion strategy of the NCC.¹³ Considering the mixed results on the impact of telecoms regulation on mobile and internet banking, the outcome of the functional regulation hypothesis is inconclusive.

6.2 Robustness

So far, we have a positive and significant relationship between the network diffusion variable and the use of SSBA. We check the robustness of this finding using (i) sub-samples regression, based on geographical regions, and (ii) alternative radial specifications on the cell tower range. While the former allows us to test the sensitivity of our findings to variations in geographic sample characteristics, the latter recognizes the possibility that the initial 10km radial specification might be too wide. For the split sample regressions, we note that each respondent is in a locality/town and a wider geopolitical region (six of them). Thus, we split our sample according to the six regions and re-run SSBA regressions. Furthermore, apart from offering a more localized measure of the infrastructure diffusion, a smaller radial specification can be viewed as a quality-adjusted measure of the infrastructure variable given that signal quality, a key determinant of communication technology usage is shaped by the physical proximity of users to network connections (Neto, et al. 2005; Grimes et al. 2012). Tables 3 and 4 present the regional results for mobile and internet applications, respectively. The results of the sub-sample regressions across geographical regions of the country generally indicate a positive effect of technology diffusion on the use of SSBA, albeit some of the marginal effects lose statistical significance, especially in the southern regions. This result seems to reflect the geographical imbalance in the distribution of banking infrastructure, which in turn affects the need for SSBA. For example, the bank branch data available from the CBN indicates that there are, on average, 0.348 bank branches within a 5km radius of all sampled households across Southern Nigeria. This dwarfs the average of 0.11 across the Northern regions. Thus, we conjecture that the relatively higher concentration of banking infrastructure in Southern Nigeria appears to dampen the demand for SSBA.

¹³ <https://www.ncc.gov.ng/media-centre/news-headlines/1008-danbatta-shares-experience-on-regulatory-model-for-nigeria-s-digital-inclusion>

Table 2. *Baseline results*

	(1)	(2)	(3)	(4)	(5)	(6)
		Mobile Banking			Internet Banking	
Log (cell tower_5km)	0.030*** (0.003)	0.021*** (0.003)	0.017*** (0.002)	0.010*** (0.002)	0.005** (0.002)	0.005** (0.002)
Log (service charge)	-0.262*** (0.019)	-0.180*** (0.019)	-0.168*** (0.016)	-0.097*** (0.010)	-0.061*** (0.011)	-0.061*** (0.012)
Log (license fee)	-0.015*** (0.004)	-0.015** (0.005)	-0.008** (0.003)	0.010*** (0.003)	0.008** (0.002)	0.009** (0.003)
Log (distance to bank)		0.010*** (0.001)	0.010*** (0.001)		0.004*** (0.001)	0.004*** (0.001)
Income dummy		0.017*** (0.005)	0.014** (0.006)		0.006* (0.003)	0.006*** (0.003)
Log (age)		-0.050*** (0.006)	-0.052*** (0.006)		-0.034*** (0.004)	-0.033*** (0.003)
Married dummy		-0.008* (0.004)	-0.004 (0.004)		-0.006* (0.003)	-0.006** (0.004)
Log (years of edu)		0.040** (0.016)	0.033** (0.013)		0.019*** (0.005)	0.019** (0.006)
Christian dummy		0.012** (0.005)	0.011** (0.004)		-0.003 (0.003)	-0.002 (0.003)
Male dummy		0.023*** (0.004)	0.022*** (0.003)		0.005* (0.003)	0.005 (0.003)
Unemployed dummy		0.005 (0.009)	-0.004 (0.006)		0.001 (0.005)	0.003 (0.004)
Urban dummy		0.015** (0.007)	0.019** (0.006)		0.010** (0.004)	0.010** (0.004)
Regional RE	No	No	Yes	No	No	Yes
N	21844	21844	21844	21844	21844	21844
Localities	730	730	730	730	730	730
LR test statistic	806.93	1359.81	325.47	222.69	308.78	82.31
<i>p</i> -val.	0.000	0.000	0.000	0.000	0.000	0.000

Notes: Standard errors in parenthesis are clustered at the locality level. ***, **, and * indicate statistical significance at the 1%, 5%, and 10%-level, respectively.

Table 5 presents the sensitivity results where we squeeze change the radial specification of the technology variable in two directions. In columns 1 and 2, we squeeze the radial specification to around half (i.e., 2.5km), while columns 3 and 4 contain the results of an expansion of the radial specification to 10km. In both cases, the marginal effects across all re-estimated radial checks retain the positive sign and statistical significance. Interestingly, the magnitude of the marginal effects in the 2.5km specifications is larger, indicating that closer proximity to network infrastructure will plausibly increase the use of SSBA. The above additional checks indicate that the effect of technology diffusion on the use of SSBA is robust to variations in geographical conditions and radial specification for the technology variable.

6.3 Addressing endogeneity

In Table 6, we present the marginal effects from instrumental variables Probit models where we address the potential endogeneity of the technology variable $diffusion_{ij}$. The coefficient estimates on the instruments have the expected negative sign and are statistically significant at the 1% level. Larger coastal landforms (i.e., larger water bodies) are associated with a lower concentration of cell towers, whereas higher ground elevation results in a greater concentration of cell towers. Additionally, areas with pre-network infrastructure are found to have greater diffusion of network technology. The Kleibergen-Paap F-statistic strongly rejects the null of weak instruments, while the Hansen J-test statistics indicate that the over-identifying restrictions are valid. Again, the results are qualitatively consistent with the baseline results which indicate that higher technology diffusion is associated with greater use of SSBA. However, the technology variable in the internet regression loses statistical significance while the mobile result retains its statistical significance. Given that different cell towers are required to deliver mobile services and internet services¹⁴, it appears that the endogeneity bias seems to be more serious for mobile infrastructure than internet infrastructure.

6.4 Exploring channels: smartphone ownership, service quality, and conflict

It is also useful to know the channels through which technology diffusion shapes the use of SSBA. For instance, smartphone ownership has increased in recent years, fostered by benefits accrued from facilitating access to internet services. Hübler and Hartje (2016) show that smartphone ownership contributes to a significant increase in the per capita household in rural households. Lee et al. (2021) find that individuals with smartphones enjoy greater access to banking products and easily access such products through online platforms, compared to those who did not own smartphones. Consequently, we expect the positive relationship between infrastructure and the use of SSBA to be more prominent among users who own smartphones. To test the channel effect of smartphone ownership, we augment our baseline regressions with an interaction term between smartphone ownership and the technology diffusion measure. The smartphone ownership variable is denoted as a dummy variable which takes the value of 1 for respondents who own a smartphone and zero otherwise.

¹⁴ Internet services are mainly delivered by 3G and 4G networks, while mobile services are delivered via all network types, including 2G.

Table 3. *Regional regressions- mobile banking*

	(1)	(2)	(3)	(4)	(5)	(6)
	SS	SE	SW	NE	NW	NC
Log (cell tower_5km)	0.002 (0.006)	0.039*** (0.008)	0.003 (0.004)	0.037** (0.015)	0.012 (0.009)	0.016* (0.009)
Log (distance to bank)	0.008** (0.004)	0.005 (0.005)	0.012*** (0.002)	0.005** (0.002)	0.013*** (0.003)	0.010** (0.003)
Log (service charge)	-0.128** (0.068)	-0.177*** (0.018)	-0.107*** (0.010)	-0.184*** (0.051)	-0.118** (0.048)	-0.263*** (0.064)
Log (license fee)	0.049*** (0.011)	-0.039** (0.016)	0.034*** (0.004)	-0.078** (0.037)	0.003 (0.013)	-0.006 (0.027)
Income dummy	-0.016 (0.012)	0.010 (0.014)	0.026*** (0.007)	0.044** (0.017)	0.024* (0.013)	-0.005 (0.013)
Log (age)	-0.067*** (0.010)	-0.059*** (0.012)	-0.067*** (0.012)	-0.060*** (0.010)	-0.001 (0.006)	-0.064*** (0.008)
Married dummy	-0.005 (0.009)	-0.004 (0.005)	-0.017** (0.008)	0.020** (0.007)	-0.004 (0.004)	-0.008 (0.006)
Log (years of edu)	0.174** (0.065)	0.043 (0.144)	0.143*** (0.003)	0.024 (0.031)	0.016 (0.080)	0.051 (0.140)
Christian dummy	-0.013** (0.005)	-0.017 (0.019)	0.005 (0.009)	0.032*** (0.005)	0.016 (0.013)	0.032*** (0.008)
Male dummy	0.011 (0.010)	0.034*** (0.006)	0.032*** (0.006)	0.031** (0.011)	0.012 (0.014)	0.006** (0.003)
Unemployed dummy	-0.019 (0.014)	0.011 (0.022)	0.047*** (0.004)	-0.022** (0.125)	-0.014 (0.014)	-0.027 (0.018)
Urban dummy	0.036** (0.020)	0.004 (0.015)	0.010 (0.014)	0.037*** (0.008)	0.006 (0.015)	0.017 (0.023)
N	3473	2888	3776	3701	4017	3989
Localities	120	100	130	100	140	140
LR test statistic	27.93	21.05	14.66	46.81	12.07	51.84
<i>p</i> -val.	0.000	0.000	0.000	0.000	0.000	0.000

Notes: This table contains split sample regressions based on the geopolitical zones in Nigeria.

SS=South-South, SE=South-East, SW=South-West, NE=North-East, NW=North-West, NC=North-Central.

Standard errors in parenthesis are clustered at the locality level. ***, **, and * indicate statistical significance at the 1%, 5%, and 10%-level, respectively.

Table 4. *Regional regressions- internet banking*

	(1)	(2)	(3)	(4)	(5)	(6)
	SS	SE	SW	NE	NW	NC
Log (cell tower_5km)	0.005** (0.002)	0.005 (0.008)	0.013*** (0.003)	0.005 (0.011)	-0.004 (0.004)	0.013* (0.008)
Log (distance to bank)	0.002 (0.002)	-0.001 (0.005)	0.002 (0.002)	0.004 (0.006)	0.003** (0.001)	0.003 (0.002)
Log (service charge)	-0.078 (0.050)	-0.085** (0.049)	-0.068** (0.021)	-0.058** (0.022)	-0.038** (0.017)	-0.040* (0.016)
Log (license fee)	0.009* (0.005)	0.035** (0.012)	-0.005* (0.003)	0.042** (0.016)	0.017*** (0.003)	0.015 (0.017)
Income dummy	0.015 (0.010)	0.003 (0.005)	-0.003 (0.008)	0.008 (0.014)	0.007* (0.004)	-0.007 (0.011)
Log (age)	-0.029*** (0.005)	-0.043** (0.019)	-0.042*** (0.005)	-0.041** (0.013)	-0.014** (0.005)	-0.027*** (0.007)
Married dummy	-0.012** (0.06)	-0.012 (0.016)	-0.008* (0.005)	-0.001 (0.010)	-0.004 (0.004)	-0.002 (0.006)
Log (years of edu)	0.055*** (0.010)	0.089*** (0.017)	0.073** (0.023)	0.023 (0.021)	0.005 (0.006)	0.046 (0.028)
Christian dummy	-0.018 (0.017)	<i>Omitted</i>	-0.007 (0.006)	-0.010 (0.009)	-0.010 (0.006)	-0.003 (0.010)
Male dummy	-0.002 (0.007)	-0.012** (0.004)	0.005 (0.006)	0.009 (0.012)	0.005 (0.009)	0.018** (0.009)
Unemployed dummy	0.006 (0.015)	0.0001 (0.028)	0.001 (0.013)	-0.006 (0.009)	0.009 (0.006)	0.003 (0.016)
Urban dummy	0.009* (0.005)	0.029** (0.014)	-0.020 (0.013)	0.017 (0.014)	0.018** (0.009)	0.004 (0.015)
N	3473	2870	3776	3701	4017	3989
Localities	120	100	130	100	140	140
LR test statistic	1.30	5.25	19.08	8.99	0.001	11.60
<i>p</i> -val.	0.127	0.011	0.000	0.001	0.986	0.000

Notes: This table contains split sample regressions based on the geopolitical zones in Nigeria.

SS=South-South, SE=South-East, SW=South-West, NE=North-East, NW=North-West, NC=North-Central.

Standard errors in parenthesis are clustered at the locality level. ***, **, and * indicate statistical significance at the 1%, 5%, and 10%-level, respectively.

Table 5. *Radial checks*

	(1)	(2)	(3)	(4)
	2.5km radius		10 km radius	
	Mobile	Internet	Mobile	Internet
Log (cell tower)	0.022*** (0.004)	0.006 (0.004)	0.010*** (0.001)	0.003** (0.001)
Log (distance to bank)	0.010*** (0.001)	0.004** (0.001)	0.010*** (0.002)	0.004*** (0.001)
Log (service charge)	-0.168*** (0.018)	-0.061*** (0.008)	-0.169*** (0.209)	-0.061*** (0.012)
Log (license fee)	-0.006 (0.005)	0.009** (0.003)	-0.009** (0.003)	0.008*** (0.002)
Income dummy	0.014** (0.004)	-0.007 (0.005)	0.014** (0.006)	0.007** (0.003)
Log (age)	-0.052*** (0.006)	-0.032*** (0.006)	-0.052*** (0.006)	-0.032*** (0.006)
Married dummy	-0.004 (0.062)	-0.006* (0.004)	-0.004** (0.002)	-0.006** (0.004)
Log (years of edu)	0.033 (0.038)	0.019** (0.005)	0.033** (0.012)	0.019*** (0.003)
Christian dummy	0.012*** (0.003)	-0.002 (0.003)	0.011* (0.006)	-0.003 (0.003)
Male dummy	0.022*** (0.004)	0.005** (0.002)	0.022*** (0.003)	0.005* (0.003)
Unemployed dummy	-0.004 (0.5824)	0.003 (0.004)	-0.004 (0.005)	0.003** (0.002)
Urban dummy	0.023*** (0.003)	0.011*** (0.002)	0.023** (0.006)	0.011*** (0.003)
N	21844	21844	21844	21844
Localities	730	730	730	730
LR test statistic	331.92	82.50	349.99	82.52
<i>p</i> -val.	0.000	0.000	0.000	0.000

Standard errors in parenthesis are clustered at the locality level. ***, **, and * indicate statistical significance at the 1%, 5%, and 10%-level, respectively.

Table 6. *Instrumental variables regression*

	(1)	(2)
	Mobile	Internet
Log (cell tower_5km)	0.267** (0.078)	0.108 (0.091)
Log (distance to bank)	0.079*** (0.010)	0.042*** (0.012)
Log (service charge)	-1.535*** (0.158)	-0.726*** (0.128)
Log (license fee)	-0.171** (0.051)	0.077 (0.048)
Income dummy	0.138** (0.040)	0.072* (0.041)
Log (age)	-0.437*** (0.458)	-0.409*** (0.050)
Married dummy	-0.060 (0.037)	-0.065* (0.039)
Log (years of edu)	0.340** (0.139)	0.229*** (0.061)
Christian dummy	0.106** (0.042)	-0.031 (0.041)
Male dummy	0.198*** (0.030)	0.065* (0.035)
Unemployed dummy	0.040 (0.076)	0.016 (0.064)
Urban dummy	0.033 (0.094)	0.070 (0.099)
Water body	-0.193** (0.076)	-0.194** (0.076)
Ground elevation	0.428*** (0.040)	0.428*** (0.040)
Pre-sample infrastructure	0.317*** (0.006)	0.317*** (0.006)
F-test of instruments	1115.59*** (0.000)	1115.59*** (0.000)
Hansen <i>J</i> -test (p-val.)	0.467	0.090
N	21844	21844
Localities	730	730

Standard errors in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

By the same token, the impact of mobile and internet banking usage may depend on the quality of service provided by the mobile operators and can be potentially augmented through better service quality. For example, better service quality may improve the extent to which individuals connect to relevant banking and financial products. On the other hand, poor service quality reduces the ability of individuals to access broadband services, such as SSBA's. Our measure of service quality is based on the published state-level service quality tables, obtained from the NCC website. Specifically, we use the Dropped Call Rate (CSSR) (%), which is the percentage of call failures, relative to total calls initiated. This measure offers a proxy for the stability, connectivity, and signal strength of available networks.

Finally, we explore the role of conflict incidence as a channel that influences the strength of the relationship between infrastructure and SSBA use. Households living in conflict-prone areas will plausibly have limited physical access to banking services and infrastructure (Floreani et al. 2021). Accordingly, during times of conflict people may use technology to overcome challenges resulting from the limited access to physical bank locations by increasing the probability of accessing financial services and completing banking transactions using online channels such as receiving remittances (Ghorpade, 2017). To measure conflict incidence, we use the total number of conflict fatalities at the locality level, downloaded from the Uppsala Conflict Data Program’s Georeferenced Event Dataset (UCDP GED)¹⁵. The results of these augmented regressions are presented in Table 7. To conserve space, we suppress the coefficients on the other variables, focusing instead on the interaction terms. We find that, for both models, the coefficients on the interaction terms cell tower × smartphone, and cell tower × conflict are positive and statistically significant at the 1% level. However, the results on the network interaction cell tower × network quality exhibit mixed signs, albeit both coefficients are statistically insignificant. These estimates indicate that smartphone ownership and the presence of civil conflict are plausible channels through which the diffusion of network technology shapes the use of SSBA.

Table 7. *Channels*

	(1) Mobile	(2) Internet
smartphone	0.748*** (0.050)	0.639*** (0.057)
network quality	0.057 (0.044)	0.018 (0.085)
conflict	0.007*** (0.002)	0.001 (0.001)
cell tower × smartphone	0.018*** (0.001)	0.010*** (0.000)
cell tower × network quality	-0.001 (0.003)	0.001 (0.001)
cell tower × conflict	0.001*** (0.000)	0.001*** (0.000)
N	21844	21844
Localities	730	730

Standard errors in parentheses

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

7. Policy Implications and Conclusion

In this paper, we utilise a micro-spatial approach to provide timely evidence of how infrastructure diffusion influences the use of SSBA. First, we observe the nuanced positive effects of infrastructure diffusion on SSBA as measured by mobile and internet banking usage. After controlling for individual

¹⁵ This commonly used measure of conflict incidence may not capture the full range of social and economic disruption, especially in cases where fatalities are not recorded. Nevertheless, it seems plausible that areas recording high social conflict fatalities do so because of higher conflict incidence, our key interest. Thus, this measure should capture how households dwelling in such areas may employ SSBA to access services versus the dangers of physically moving around to access financial services. See <https://www.theguardian.com/sustainable-business/somalia-remittances-financial-institution-operate-conflict-zone>

and regional factors, the positive effect of infrastructure diffusion remains stronger for mobile banking usage. Second, we document the heterogeneous effects of transaction costs on SSBA. While on the one hand, the purported increase in transaction costs associated with the distance to physical bank locations is linked to a significant rise in the use of SSBA, on the other hand, we find that higher subscription costs are associated with a decline in the use of SSBA. Specifically, the large marginal effects associated with subscription costs effects indicate that user subscription cost will likely pose a challenge for the use of SSBA. This finding is significant from a policy viewpoint given that the poverty rates associated with our study context are reportedly one of the highest in the world (World Bank, 2021).

Furthermore, our results are informative of the extent to which the use of SSBA may be accentuated by policy responses to improve the ownership of mobile devices such as smartphones. As our results show, smartphone ownership may intensify the use of mobile and internet banking. In other words, government policies aimed at encouraging the use of SSBA may want to encourage the diffusion and ownership of smartphone ownership across different regions of the country. Overall, our work is only a first step to understanding the extent to which infrastructure diffusion might impact the use of SSBA. It contributes to the literature by uncovering the heterogeneous impacts of infrastructure diffusion on self-service applications within an emerging economy. More work is needed to understand other dimensions of the infrastructure-SSBA usage nexus not fully understood in our study. For instance, future studies could explore cross-country heterogeneity in the role of functional regulation which is inconclusive in our analysis. Such a line of inquiry may facilitate a greater understanding of how regulation impacts the use of SSBA in a more causal way.

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