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ABSTRACT

The Welfare Effects of Mobile Broadband Internet: Evidence from Nigeria*

This paper estimates the impacts of mobile broadband coverage on household consumption and poverty in Nigeria, the largest economy and mobile broadband market in Africa. The analysis exploits a unique dataset that integrates three waves of a nationally representative longitudinal household survey on living standards with information from Nigerian mobile operators on the deployment of mobile broadband (3G and 4G) coverage between 2010 and 2016. The estimates show that mobile broadband coverage had large and positive impacts on household consumption levels which increased over time, although at a decreasing rate. Mobile broadband coverage also reduces the proportion of households below the poverty line, driven by higher food and non-food consumption in rural households. These effects are mainly due to an increase in labor force participation and employment, particularly among women.

JEL Classification: D12, F63, I31, L86, O12

Keywords: poverty, household consumption, mobile broadband, Africa, Nigeria

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1. Introduction

A growing body of literature has documented the impacts of internet access on a host of economic outcomes.[1] Some empirical evidence suggests that the internet—like other skill-biased technological innovations—tends to benefit more educated workers but may lead to displacement effects among their less educated peers. This mechanism has often been cited to explain why poverty reduction has been sluggish among the least developed areas of the world despite significant improvements in internet connectivity.[2] On the other hand, more recent evidence has shown that the internet has enabled faster job creation and increased economic activity in Africa, as well as higher productivity and export growth among firms in Africa (Hjort and Paulsen, 2019). However, little is known about the effects of the internet on household and individual welfare, especially among the poorest populations.

In this paper, we provide new evidence on the impacts of mobile broadband coverage on household consumption and poverty in Nigeria, the largest economy and mobile broadband market in Africa. Using a difference-in-difference strategy, we exploit a unique data set that integrates three waves of a nationally representative longitudinal household survey on living standards—the General Household Survey or GHS—with information from Nigerian mobile operators on the deployment of mobile broadband coverage during the 2010-2016 period. The data allow us to match the location of each household with the coverage provided by each mobile site, to determine with precision the time when individual households began receiving coverage. Individual coverage of mobile broadband is defined as the provision of 3G or 4G coverage, which enables high-speed access to the internet, and excludes 2G coverage as it only provides for limited internet browsing and applications.

We find that mobile broadband coverage had large and positive impacts on household consumption levels. Households that had at least one year of mobile broadband coverage experienced an increase in total consumption of about 6 percent. These effects increase over time, though at a decreasing rate. Coverage also reduces the proportion of households below the poverty line by about 4.3 percentage points for extreme poverty and 2.6 percentage points for moderate poverty after one year of gaining mobile broadband coverage. Moreover, the gains on total and food consumption are progressive, since they tend to be larger for initially poorer rural households.

We also explore some of the underlying mechanisms through which mobile broadband coverage can enhance welfare, including employment and prices. We find that improvements in labor market outcomes contribute to the increase in consumption by raising the purchasing power of households. Households in areas covered by mobile broadband internet witnessed an increase in labor force participation and wage employment of about 3.3 and 1.4 percentage points respectively, with these effects materializing three or more years after being covered.

A potential concern regarding the difference-in-difference strategy is that mobile broadband coverage is not rolled out randomly, since operators tend to target more prosperous areas first, which in turn are likely to have higher consumption levels and lower poverty rates. However, when comparing pre-existing trends in key variables between covered and uncovered areas, we find that the differences are

[1] See Bertschek et al. (2017) for a comprehensive review of the literature.
[2] For example, World Bank World Development report "Digital Dividends" (2016) argues that without complementary policies (such as in education, business environment, etc.), many benefits of the internet may go unrealized and inequality may increase.

not statistically significant, and thus the assumption of similar pre-treatment trends holds for the analysis. Our results are robust to specifications including self-reported access to internet, as well as to estimations of a quasi-random approach looking at the impact of mobile broadband coverage on households that were not targeted by operators, but instead benefitted from coverage unintentionally. The results of these complementary models support the finding that mobile broadband coverage had positive impacts on consumption and poverty. Taking advantage of the longitudinal structure of the data we can also rule out that our results are driven by endogenous migration where wealthier households might move into areas with strong 3G/4G coverage.

This paper makes several important contributions to the literature. First, to the best of our knowledge, this is the first study to identify the effects of a large-scale roll-out of broadband internet on household-level poverty and consumption growth in Africa. Second, this is also the first study to focus on the welfare impacts of mobile broadband on households instead of fixed broadband access. This is key since the former is by far the most important form of internet access in Africa.[3] Third, it exploits a rich data set that has several advantages over those of existing studies. It is a longitudinal dataset that tracks households in three waves over a 7-year period. This allows to control for unobserved heterogeneity at the household level, which would otherwise introduce a bias in the estimated effects. In addition, by matching the exact location of each household with varying signal strength of mobile broadband internet at the maximum offset of 45 meters, the results are not affected by the type of measurement error that occurs when relying on proxy variables for coverage, such as the average distance of the household (or household's district centroid) to the nearest cellular tower or backbone.

Our findings also contribute to the broader literature assessing the microeconomic effects of mobile internet, especially in developing countries. A small number of studies, notably Beuermann et al (2012) and Blumenstock et al (2020), have found that mobile technology improves welfare in terms of consumption and poverty, though these relate to mobile coverage more generally (including 2G) rather than mobile broadband coverage. In terms of the mechanisms through which the internet can enable welfare improvements, the literature is somewhat more extensive. For instance, studies have found the internet can improve labor market outcomes (Paunov and Rollo 2014; Fernandes et al. 2019; Chun and Tang 2018; Viollaz and Winkler 2020) and the functioning of rural markets (Kaila and Tarp 2019; Goyal 2010; Ritter and Guerrero 2014; Salas-Garcia and Fan 2015), specifically regarding price information, access to inputs and consumers (Aker and Mbiti 2010; Aker 2011; Debo and Van Ryzin 2013) and access to capital markets (Hasbi and Dubus, 2019; Alibhai et al. 2018). Some studies have also looked at heterogenous impacts, finding for example stronger wage effects for low-income households (De los Rios 2010; Klonner and Nolen 2010; Marandino and Wunnava 2014) and female workers benefitting from employment effects (Menon 2011).

Finally, this study represents an important contribution to the policy discussion about the costs and benefits of expanding internet access. It provides a framework that can be used and expanded to assess the impact of mobile broadband coverage in low- and middle-income countries, particularly as more granular data become available on coverage and connectivity. The findings also have important implications for governments and the international community, especially those looking to prioritize

[3] In 2017, the number of fixed broadband subscriptions per 100 inhabitants in Africa was 0.4, while the corresponding figure for active mobile broadband subscriptions was 34 (ITU, "Measuring digital development Facts and figures", 2019).

internet access and connectivity as a driver of poverty reduction and economic prosperity.[4] By showing that mobile broadband coverage can in fact reduce poverty and improve consumer welfare, this study provides important evidence on the benefits of connectivity that policy makers can consider when seeking to achieve universal internet access.

The rest of this paper is structured as follows. Section 2 describes the data sources while section 3 presents the estimation strategy. Section 4 presents the results, and section 5 concludes.

2. Data

Our analysis relies on the overlap of two data sets for Nigeria: the General Household Survey (GHS) and the geographical coverage of mobile networks. Linking the location and the chronology in these datasets allows us to determine the treatment of interest for our analysis i.e. the availability of mobile broadband at the exact household's location.

General Household Survey Data

Our analysis uses three waves of the General Household Survey (GHS) of Nigeria (2010/11, 2012/13, and 2015/16) which is a nationally representative longitudinal survey.[5] The GHS is a dedicated living standards survey which provides detailed information on households' consumption as well as other key demographic and socio-economic indicators of their members including education, labor market outcomes and access to the internet. The GHS also includes a community survey which provides data on prices from local markets as well as on community characteristics. In the initial round of the GHS survey (2010/11) 4,916 households completed interviews. The GHS had minimum attrition as most households interviewed in wave 1 were re-interviewed in the second wave (N=4,851) and the third wave (N=4,581).[6]

Each wave includes two visits to each household during the autumn months (post-planting) and the spring months (post-harvesting).[7] Some important factors such as labor market outcomes, food consumption, and expenditures were collected during both visits. Total consumption includes all food consumption and purchases (including meals outside home) as well as non-food expenditure (e.g., education, housing rents, clothing, fuel, utilities, transportation, communication, reaction and other services). Total consumption is estimated using the mean of two visits for each of the three waves of the GHS. Poverty status of households is calculated based on international poverty lines of US$1.90 and US$3.20 per day (2011 PPP) and after applying the Consumer Price Index (CPI) to adjust for both spatial and temporal inflation. Table 1 provides summary statistics of key indicators derived from the GHS survey.

[4] Examples of such targets include: the UN Sustainable Development Goals (SDG 9 includes Target 9c to "*Significantly increase access to information and communications technology and strive to provide universal and affordable access to the internet in least developed countries by 2020*"); the Broadband Commission for Sustainable Development 2025 targets for "Connecting the Other Half", and; the World Bank's Digital Economy for Africa (DE4A), which aims to ensure that all Africans have universal and affordable access to ICT by no later than 2030.

[5] More information on the GHS including design, survey instruments, datasets and methodology can be found in this link: http://surveys.worldbank.org/lsms/programs/integrated-surveys-agriculture-ISA/nigeria

[6] Given the panel nature of the survey, some households moved from one wave to the next and efforts were made to track these movers.

[7] All households were visited twice regardless of whether they participated in agricultural activities.

For the analysis, the number of households is reduced slightly to 13,732 due to missing values in some of the key variables, which is equivalent to 4.35% of the sample (6.63% for individuals aged 15-64).

Mobile Broadband Coverage Data

Nigeria is the largest mobile market in Africa. At the end of 2019, there were more than 170 million mobile connections (60% of which used 3G or 4G mobile broadband technologies) and the country accounted for around one in six mobile subscriptions on the continent.[8] Figure 1 shows how the adoption of 2G and 3G/4G technology evolved in Nigeria between 2010-2016.

In this study, we look at mobile broadband network coverage (or availability). Coverage is distinct from usage (or access), which is when an individual has a SIM card that can be used in a mobile phone to access the internet. We look at coverage because it is not determined at the household-level and because coverage captures not only the direct impacts of individuals accessing the internet but also spillover effects. The latter includes, for example: internet users sharing information with non-users and non-users benefitting from lower market prices; job creation and productivity gains among domestic firms due to more technology use and access to international markets; or more financial capital accumulation and utilization due to increased use of digital payment platforms and mobile banking.

Mobile networks can be conceptually divided in two components. The first is the Core Network that ensures the intelligence of the network, such as switching user calls or routing user data to and from the internet. The second is the Radio Access Network, which is the collection of relay sites (i.e. towers hosting base stations and radio equipment) that connects the User Terminal (e.g. mobile phones) to the core of the network. Relay sites communicate with mobile phones in their vicinity using electromagnetic signals. The quality and availability of this communication link can be affected by several factors such as distance between the relay site and the mobile phone or the presence of obstacles (e.g. hills or buildings). A geographical area is considered *covered* when the signal of any relay site is strong enough for mobile phones in that area to establish a usable connection link with that relay site. The aggregated coverage of a mobile network is calculated by adding up the coverage of all the relay sites in its Radio Access Network.

To produce the aggregate coverage data for Nigeria, first we collected network infrastructure data directly from three of the largest four MNOs in Nigeria.[9] For each individual relay site we collected

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[8] Source: GSMA Intelligence. A mobile connection is a unique SIM card (or phone number, where SIM cards are not used) that has been registered on a mobile network. Connections differ from subscribers as a unique subscriber can have multiple connections.

[9] During the period of our analysis, the average combined market share for the three operators that we collected data for was around 75% and one of them had the highest 3G coverage in the market, with 70% of the population covered. While we were unable to collect primary data for the fourth MNO (MNO-4), we collected secondary data on the coverage of MNO-4 in 2015 and 2016 and overlapped this with our coverage data set for the other operators. We did not find any locations that were covered only by MNO-4. To test if MNO-4 could have deployed in those overlapping locations before the other three MNOs, we compared the coverage of MNO-4 with the coverage of the other operators in 2012. This highlighted nine enumeration areas (less than 1%) from the GHS data set that were covered only by MNO-4. This is also likely to be an overestimate as MNO-4 will have had lower coverage in 2012. These tests therefore give us confidence that the lack of data for MNO-4 has a small effect, if any, on the accuracy of our coverage data set.

the following parameters: (i) location in geographical coordinates; (ii) height of the tower hosting the antennas; (iii) signal emitting power; (iv) antenna parameters such as the gain, azimuth, and tilt; (v) frequency band used; (vi) type of technology available (2G, 3G, or 4G), and; (vii) date of deployment.

Then, we calculated the coverage of each relay site using a Radio Propagation Model (RPM). RPMs are empirical mathematical models widely used by MNOs for planning the setup of their networks, allowing them to plan the location and characteristics of each relay site so as to maximize coverage and decrease costs. There are several RPMs available that are optimized for specific settings or technologies. We used an Irregular Terrain Model (ITM), also known as the Longley Rice model,[10] which is optimized to deliver accurate results in rural and peri-urban areas.

The ITM uses two sets of input variables. The first are the technical parameters of each individual relay site that we collected from MNOs. The second are the characteristics of the transmission medium, such as the terrain profile[11] and the type of vegetation in the area.[12] The output of the ITM model is a geocoded image showing the area covered with signal strength above a predefined threshold (see Figure 2 as an example). The predefined signal strength thresholds that we used are presented in Table 2.[13] Our approach is similar to that used by Yanagizawa-Drott (2014) to estimate the coverage of two radio transmitters in Rwanda, with the difference that mobile networks in Nigeria have tens of thousands of relay sites emitting in multiple frequencies that we overlaid to obtain the aggregated coverage.

Figure 3 shows the aggregated 3G coverage in Nigeria in 2010, 2012, and 2015. During this period, 3G coverage evolved from the main cities only to a large number of intermediate cities and rural areas. This represented an increase in population coverage from 21% to 57%. This variability is not observed for 2G, which for the same period increased from 83% to 89%. The main operators did not start rolling out 4G networks until 2016, when it was limited to urban areas.

By contrast, during the same period, penetration of fixed broadband internet in the country averaged around 2%, reaching just over 5% in 2016.[14] Mobile has therefore been the primary platform for users in Nigeria to access broadband internet services.

Linking coverage data to each household location

Figure 4 presents the location of the enumeration areas that were surveyed in the GHS and shows which had access to 3G or 4G coverage in 2010 and 2016. We consider a household to have mobile broadband coverage when it is covered by a medium or strong signal in 3G or 4G. The two data sets

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[10] P.L. Rice, A.G. Longley, "Prediction of Tropospheric Radio Transmission Loss Over Irregular Terrain – A computer method 1968," Essa Technical Report ERL 79-IT S67. Available: http://www.visuallmr.com/documentation/pathlossmodels/ntis.longleyrice.676874.pdf

[11] We used the SRTM 90m Digital Elevation Database created by NASA. See: https://cgiarcsi.community/data/srtm-90m-digital-elevation-database-v4-1/

[12] The vegetation profile used for Nigeria was Maritime Subtropical (West coast of Africa).

[13] These thresholds were chosen to fit industry standards. For reference see: BEREC, "Common Position on information to consumers on mobile coverage", 2018. Available at: https://berec.europa.eu/eng/document_register/subject_matter/berec/download/0/8315-berec-common-position-on-information-to-_0.pdf.

[14] Source: ITU World Telecommunication/ICT Indicators (WTI) Database 2019.

were linked by matching the coverage footprint for each radio bearer with the almost exact locations of households based on GPS coordinates, which are much more precise than previous studies.[15]

3. Estimation strategy

In order to estimate the impact of mobile broadband coverage on household outcomes, we estimate the following equation:

$$(1)\quad Y_{ijt} = \alpha_i + \beta_1 DT_{ijt} + \beta_2 X_{ijt} + \gamma_t + \varepsilon_{ijt}$$

where Y_{ijt} is the outcome for household *i* in local government authority (LGA) *j* in year *t,* and DT_{ijt} denotes the treatment of our interest – access to 3G or 4G coverage. This treatment is operationalized by a binary variable that takes a value of 1 if the household lives in an area covered by 3G or 4G networks (and 0 otherwise). As the impact of coverage may change or evolve over time (for example due to mechanisms taking time to translate into observed outcomes), we apply the following variations of the treatment dummy:[16]

- Takes a value of 1 if the location of a household is covered at the time of the survey (0 otherwise);
- Takes a value of 1 if the location of a household has been covered for over one year;
- Takes a value of 1 if the location of a household has been covered for over two years;
- Takes a value of 1 if the location of a household has been covered for over three years.

Equation 1 accounts for time-invariant household fixed effects and time-fixed effects, which are captured by α_i and γ_t respectively.[17] It also includes X_{ijt}, a set of time-varying household control variables. These include: household size; access to electricity; whether the household dwelling is owned; and an index measuring dwelling characteristics.[18] This is broadly in line with the controls used in the literature.[19] Further, we add access to 2G coverage to ensure that the analysis isolates the impact of upgrading coverage to 3G/4G and does not conflate it with the impact of getting 2G coverage, which can be used for voice, SMS and limited internet access (all of which could impact our outcome

[15] More specifically, we rely on GPS coordinates of households with the maximum offset of 45 meters to assign to each household the initial date of coverage (if any) by any combination of radio bearer and signal strength. In contrast, other studies have relied on data integration using buffer sizes between 1 to 5 kms in urban areas, and 1 to 20 kms in rural areas (see for instance DHS -- Demographic and Health Surveys).

[16] In addition to identifying time dynamics with dummy variables, we also measured internet access as the cumulative number of months since a given household was first covered by 3G/4G services (instead of a binary approach). The results of this analysis are presented in Table A 1 in Appendix 1.

[17] We also carry out a sensitivity analysis and estimate the model in first-differences. The results are presented in Table A 2 and are roughly similar to our fixed effects estimates. Given that we account for serial correlation in the fixed effects regression by clustering standard errors by household, the latter is our preferred strategy because it maximizes the number of observations, as not all households are included across all three waves of the survey. Moreover, any bias due to non-contemporaneous correlation between the error term and the independent variables is lower with fixed effects.

[18] The index is based on whether the household has the following: solid walls; solid roof; solid floors; access to toilet; access to water toilet, and; kerosene, electric or gas cooking fuel. Based on household responses to these questions, the index was calculated using a weighted average, with weights derived from principal component analysis. The index is used because including the different components as separate variables introduces multicollinearity in the regression.

[19] See for example for Nsabimana and Funjika (2019) and Beuermann et al (2012).

variables).[20] We also run our main specification controlling for self-reported access to the internet to check the robustness of the analysis.

This means the coefficient β_1 captures changes in outcomes at the household or individual level, controlling for unobserved household characteristics and accounting for changes over time for both treated and untreated households (i.e., a difference-in-difference estimator). In order to account for the existence of heteroskedasticity and serial correlation, we use a cluster-robust estimator with clustering at the household level.

Outcomes, mechanisms and heterogeneous effects

In terms of the dependent variable Y_{ijt}, we use two broad outcomes to measure household welfare; consumption and poverty. We explore breakdowns of consumption by looking at food and non-food consumption separately and we apply a logarithmic transformation due to large skewness and kurtosis values. For poverty, we use two measures; the first takes a value of 1 if the household per capita consumption is less than the international extreme poverty line of \$1.90 per day (measured in purchasing-power-parity) and the second takes a value of 1 if the household per capita consumption is below the low-middle income international poverty line of \$3.20 per day, which includes Nigeria.[21]

We also consider two mechanisms through which mobile broadband translates into improvements (if any) in welfare: labor market outcomes and prices. We examine the impact of 3G/4G technologies on four different labor market outcomes: (i) labor force participation, (ii) farm self-employment, (iii) salaried/wage employment, and (iv) non-farm self-employment.[22] A predominant share of the employed population (about 80 percent) are self-employed working in agriculture or in nonfarm household enterprises. The effects of mobile broadband technologies on wage/salaried employment are particularly of interest, as a shift away from self-employment to more productive wage/salaried employment in private and public services is deemed as one potential way to reduce poverty rates across the country (World Bank 2015).

Besides its effects on the labor market, mobile broadband can also help ease information asymmetry problems, improving price information and making price setting mechanisms more efficient. This may induce lower prices (see for example Aker and Mbiti 2010). The internet may also impact prices if it induces greater competition in the marketplace, through reductions in transaction and information costs, which facilitate trade and firm entry. To test this potential causal channel, we assess the impact of 3G/4G coverage on the unit prices of food products by estimating the following model:

$$(2)\quad P_{jt} = \alpha_j + \beta_1 DT_{jt} + \beta_2 X_{jt} + \gamma_t + \varepsilon_{jt}$$

[20] We also ran an alternative model where we restricted our sample to households that had access to 2G coverage across all three waves and the results were consistent.

[21] https://blogs.worldbank.org/developmenttalk/richer-array-international-poverty-lines.

[22] For this analysis, labor force participation is defined as those working-age (15-64) individuals who were employed or unemployed (looking for a job) in the past 7 days. Farm self-employment refers to working-age individuals who worked on a farm owned or rented by their own household members during the past 7 days and non-farm self-employment includes working-age individuals who worked on their own account during the last 7 days. Lastly, working-age individuals who worked for someone who was not their family members during the last 7 days were considered to be salaried/wage workers.

where P_{jt} is the log of the unit price of a food product in LGA *j* at wave *t* and DT_{jt} is the share of people who live in the LGA covered by 3G/4G for different lengths of time (e.g., one year or more; 2 years or more; 3 years or more). The key food products include the five most consumed products among the poor who live under the $1.90 poverty line: rice, palm oil, beef, white beans, and groundnut oil. X_{jt} includes the same set of time-varying household control variables as included in Equation 1 but now aggregated to the LGA level.

Another way in which mobile can drive improvements in individual and household welfare is by enabling access to financial services, especially mobile money. Studies have shown that mobile money reduces transaction costs for users and helps households to better manage their cash-flows more effectively, enabling them to smooth consumption, manage risk and build working capital. It can also provide for higher incomes through remittances.[23] However, the adoption of mobile money in Nigeria was limited during the 2010-2016 period. Evidence from the World Bank Findex survey shows that the proportion of adults using mobile money in Nigeria was 2% in 2014 and 5% in 2017.[24] Given such low levels of usage, it is very unlikely that any impact of mobile broadband coverage on consumption or poverty was driven by mobile money access.

In terms of the labor market and price mechanisms, we run each of our regressions on several sub-samples to explore heterogeneous effects by: gender; initial level of consumption of each household; region; age; area (urban/rural) of residence; education and literacy status of the household head or respondent, and the presence of children under the age of three in any of the three waves.

Pre-treatment trends

By focusing on mobile broadband coverage and not mobile broadband usage (which is a household choice), the estimation strategy follows an intention-to-treat (ITT) framework, similar to Beuermann et al (2012). However, mobile operators do not expand or upgrade their networks randomly. Instead, they are likely to first target areas that will generate higher expected returns, and one would expect households in these areas to have higher levels of consumption and lower incidences of poverty.

In order for the ITT framework to produce unbiased results, we therefore rely on the assumption that outcomes for the 'treated' group of households (those that receive coverage) would have evolved in the same way as the 'control' group of households (those that do not receive coverage) if they had not benefitted from 3G or 4G coverage. This is not possible to test, but it is more likely to hold if the two groups have similar pre-treatment trends. We therefore exploit the fact that we have three waves of survey data and apply a test based on the approach proposed in Angrist and Pischke (2008). Specifically, we estimate:

$$(3)\quad Y_{ijt} = \alpha_i + \beta_1 DT_{ijt+1} + \beta_2 X_{ijt} + \gamma_t + \varepsilon_{ijt}$$

In equation 3, we test whether changes in the outcome of interest between Wave 1 and Wave 2 are predicted by getting coverage between Wave 2 and Wave 3. If the coefficient is statistically significant for consumption, this would suggest that consumption 'leads' coverage and so one could not conclude that coverage has a causal impact on consumption. On the other hand, if the coefficient is not

[23] For a detailed review of the literature on the economic impact of mobile money, see Aron (2018).
[24] https://globalfindex.worldbank.org/

statistically significant, and if the results for equation 1 still hold when restricting the analysis to Waves 2 and 3, then this gives us confidence that the link between coverage and welfare is causal. If the parallel trends assumption holds, β_1 would be statistically insignificant.

In addition to testing for similarity of pre-treatment trends, we also run additional specifications that exploit the fact that some households get 'unintentional' mobile broadband coverage, which is potentially quasi-random. The strategy relies on the fact that mobile coverage is heavily influenced by the distance of a household to the nearest mobile site, due to the characteristics of the signal transmission medium. In particular, some households get coverage even though they were not specifically targeted by operators to receive coverage but did so due to exogenous factors (such as terrain features). In Appendix 2, we present further details of this approach along with some preliminary results. [25]

4. Results

In this section, we present the principal results for nine outcomes and mechanisms of interest discussed above in Table 3-12, with and without additional control variables. All other tables in this section include control variables. In Table 13-17, we examine results for different subsamples. For these exercises, we split our sample by the gender of the household head, followed by a split at the median per-capita consumption in the first wave. We then look at the South and North of Nigeria separately. The split by age is roughly based on the median value in the full sample, which is 50 years for household heads and 30 years for working-age individuals. We also look at rural and urban areas separately and split the sample by education level. Finally, we also split the sample based on the composition of household (whether a given household has children under 3 years old). Given restrictions in data availability, for the latter we used educational attainment in wave three.[26] Lastly, we present results for pre-trends in Table 18. Additional robustness checks are presented in the appendices to this paper.

Main results

We start by presenting results for our three measures of consumption, measured in logarithmic scale: Total consumption and its components, food and non-food consumption. The results are almost identical for the specifications with and without control variables. The discussion will focus on the former, which shows slightly smaller effects, as our preferred specification.

According to Tables 3 to 5, there are significant impacts of 3G/4G coverage when the number of years of coverage is considered. If a household had been covered for at least one year, we find a large increase in food and non-food consumption, statistically significant at the 5 percent level. Having at least one year of coverage increases total consumption by 5.8%, food consumption by 6.2% and non-food consumption by 6.3%. After two years and three years of coverage, these estimates increase. Food consumption increases by 7.8% after two years of coverage and by 8.9% after three years of

[25] Another source of endogeneity that could confound the causal linkage between mobile internet coverage and welfare is migration. A small fraction of households (5%-8%) moved between waves and some of them may have migrated to areas covered by 3G/4G because they were wealthy enough to do so. To account for this possibility, we explore if 3G/4G coverage has impact on migration. See Appendix 3 for further discussion on this topic.

[26] Note that because the variables these splits are based upon are not necessarily available for all respondents, the sum of the observations in the two subsamples is mostly smaller than the total observations in Table 3-12.

coverage, while non-food consumption increases by 6.1% and 6.9% respectively. Therefore, the effect of access to 3G/4G mobile networks, while not being immediate, manifests itself after one year and thereafter increases at a decreasing rate over time.

If the increase in consumption is experienced by poor households, these results may imply that access to 3G/4G mobile networks would reduce poverty. We look at the two poverty lines commonly used by the World Bank for global poverty monitoring: the US$1.90-a-day and the US$ 3.20-a-day poverty lines (Table 6 and Table 7, respectively). For the lower poverty line (US$ 1.90), Table 6 shows consistently negative impacts. Having been covered for at least one year reduces the proportion of households in extreme poverty by 4.3 percentage points on average (statistically significant at the 5 percent level). The effect increases to 6.9 percentage points after at least one year of coverage. It then stays constant with an estimated effect of 6.8 percentage points after at least three years of coverage. All these effects are significant at the 1 percent level.

For the US$3.20 poverty line, the effects are also negative, but lower in magnitude and without statistical significance at the standard levels. Having coverage reduces the proportion of poor households by an estimated 1.7 percentage points. This effect increases to 2.6 percentage points, after at least one year of coverage. For two years or more it drops to 2 percentage points and for at least three years it returns to 2.6 percentage points. The increase in consumption due to 3G/4G coverage therefore leads to poverty reduction, especially for the more extreme poverty line. These results imply that poorer households benefitted most from mobile broadband coverage.

The magnitude of our results can be compared with those shown by Beuermann et al. (2012) and Blumenstock et al. (2020), with the difference that they estimate the effect of access to mobile coverage rather than mobile broadband coverage. Using data from rural Peru between 2004 and 2009, Beuermann et al. (2012) find that mobile phone expansion increases real consumption by 11 percent and reduced the incidence of poverty by 8 percentage points and the incidence of extreme poverty by 5.4 percentage points. Using data from 14 rural and geographically isolated areas in the Philippines between 2016 and 2018, Blumenstock et al. (2020) find that the introduction of a new phone tower led to an increase in household income of 17 percent, and increased household expenditures by 10 percent.

Channels of impact

Turning to the different causal channels through which access to 3G/4G translates into greater welfare, we examine if mobile broadband coverage affects labor and employment outcomes as well as prices. We find that individuals (ages 15 to 64) from households that live in areas covered by 3G/4G technologies are more likely to be in the labor force and to have wage/salaried employment. Table 8 shows a significant positive effect on labor force participation after at least two years of coverage. Similarly, those individuals who live in areas covered by 3G/4G for three years or more are more likely to work in wage/salaried jobs, but not in self-employment jobs (Table 9-11). These results are almost identical for the specifications with and without control variables. The estimates for having coverage of any length and for having it for at least one year are very close to zero and statistically insignificant. However, having coverage for at least two years increases the proportion of individuals in the labor force by 2.6 percentage points, and for at least three years, this increases to 3.3 percentage points. By the same token, the proportion of individuals who have wage/salaried employment increases by 1.4 percent when they live in areas covered by 3G/4G technologies for three years or more. These results point to labor force participation and wage/salaried employment as a likely causal channel for the previous results, but arguably not the only one as it does not explain the statistically significant results for consumption and poverty after one year of coverage.

In terms of the effects of mobile broadband coverage on food prices, we do not find any significant effect on the unit prices of the key food products. Across all the five most consumed food products, none of the estimated effects turns out to be significant (see Table 12).

Results for different subsamples

Starting with the three consumption outcomes, according to the results in Table 13-15, we note a lack of statistical significances on the consumption and poverty levels of female-headed households. This is not only an artefact of the lower sample size, as the point estimates are also much lower - in some cases a whole order of magnitude.[27] One possible reason for this is that in Nigeria, women can face significant barriers to using mobile internet relative to men, which might prevent them from reaping the benefits of 3G/4G coverage. For example, in 2017 the gender gap in mobile internet usage in Nigeria was 32% (meaning that women were 32% less likely than men to use mobile internet).[28]

The percentage change in total and food consumption is larger for the initially poorer (i.e. with consumption levels below the median in wave one) households. The results are almost identical between the two groups for non-food consumption. For food consumption, the effects are around twice the size. This result concurs with those on poverty discussed above. We do not detect any important differences in the effects on consumption between the North and South. In general, the results are less precise for each region separately than for the pooled sample. This may be driven not only by a lower sample size, but also by less variability within each region. The age of the household head does not seem to play an important role either, with the exception of extreme poverty where households with younger heads of family observer a higher decline in poverty.

We find a striking difference between urban and rural households. We find consistently positive point estimates of large magnitude for rural households, with statistical significance at the 1 percent or 5 percent level for all treatments of one year or longer. The results for urban households are mostly statistically insignificant, even after adjusting for the sample size, and not very consistent. The exception is for the effect of more than three years of coverage on food consumption, which is surprisingly negative and significant at the 1 percent level. The results in the final columns indicate, first, that households in which the head has at least a primary education benefit from increased consumption (after one year of coverage), while households in which the head has less than a primary education may have benefitted after three years of coverage (similar to female headed households, we have a much smaller sample size).[29] No systematic effect can be found for literacy status. Interestingly, the effect on food consumption is concentrated on households with children under 3 years of age, while the effect on non-food consumption is concentrated on households with no such children.

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[27] One can counterfactually compute standard errors for different hypothetical sample sizes, assuming that all the other components remain the same. If the female headed households had the same sample size as the male headed ones (i.e. 10,772), even the largest point estimate for total consumption after at least three years of coverage (0.034) would only be significant at the 10 percent level. For non-food consumption (point estimate of 0.04) it would barely at the five-percent critical value. All other positive estimates would be statistically insignificant.

[28] See GSMA (2018).

[29] The number of observations decreases dramatically when conditioning on education due to a large number of missing values.

These results are also reflected in Table 16 and Table 17 for the two poverty lines. As with the results for the whole sample, the effects are much stronger for the lower poverty line: We find a reduction between 5 and 7.7 percentage points for male headed households, but no statistically significant results, even after adjusting for the sample size, for female headed households. The reduction in extreme poverty status is greater for those initially poorer (for the initially richer these estimates have to be interpreted as a reduction in the risk of falling into poverty) and is concentrated in the South. Interestingly, here the largest effects are found for households with a younger head. The effects are concentrated in rural areas, and if the household head finished primary school, they are detectable after having had one year of coverage. Again, there is no systematic effect by literacy; and the result on food consumption for households with young children is now reflected in the effect on extreme poverty status.

In Tables A4-A7 in Appendix 1, we also show results for labor outcomes variables by groups. In these tables, gender and age refer to that of the respondent, not the household head. As before, the results are somewhat weaker despite the larger sample size. We now find that two or three years of 3G/4G coverage increase labor force participation for women. In other words, while 3G/4G coverage does not increase consumption levels of female-headed households, we find evidence consistent with the increase in consumption among male-headed households being—at least partially—driven by improved labor market outcomes for women. This result is consistent with empirical evidence for Jordan, where access to mobile broadband improved the labor market outcomes of women, but not those of men (Viollaz and Winkler, 2020). The effect of mobile broadband also appears to yield greater positive dividends on labor force participation for those individuals living in households with initially lower levels of consumption (Table A 4). Also importantly, though maybe not overly surprising, younger respondents (under 30) tend to be more likely in the labor force (Table A 4) and employed in wage/salaried jobs (Table A 6) when they are exposed to two years or more of coverage by 3G/4G whereas mobile broadband coverage increases farm self employment for older individuals after three years of coverage (Table A 5). Education levels do not play any important role, except for individuals with at least primary education after three years of coverage (we attribute the lack of statistical significance here on the much lower sample size). There are strong and statistically significant effects on agricultural self-employment after two and three years of coverage. The effects on overall labor force participation appear to be driven by households with no children under the age of three.

Pre-trends and robustness checks

In Table 18 we examine the results of the pre-trends analysis. The results are mostly in line with those found before, albeit slightly weaker given the smaller sample size. Somewhat confusingly, we find a statistically significant (at the 10 percent level) drop in food consumption for coverage at the moment of the interview. However, for coverage of more than one, two, or three years, the results are very similar to the ones found before. Most importantly, none of the results on the actual pre-trends is statistically significant at the 5 percent level or below.

Furthermore, our main results are robust to specifications including self-reported access to internet as controls, which shows the exogeneity of our treatment. Also, our results are robust to a quasi-experimental approach where we assess the impact of mobile broadband coverage on households that were not targeted by operators but instead may have benefitted from coverage unintentionally. These results are presented in Appendix 2. Finally, Appendix 3 presents results that reject tests for endogenous migration, which could be driven by wealthier households moving into areas with 3G/4G coverage.

5. Concluding remarks

This paper provides new evidence on the positive impacts of mobile broadband coverage on household consumption and poverty status in Nigeria. Unlike previous studies, it uses a data set that is nationally representative with detailed data on consumption and living standards, which tracks households over time and matches them with precise mobile broadband coverage data from operators. It finds that mobile broadband coverage had positive and significant impacts on consumption and poverty reduction, particularly among initially poorer and rural households. These results suggest that the economic benefits of mobile broadband coverage are not limited to households who already participate in more developed economic sectors outside subsistence agriculture or formal wage employment. The results are driven by improved labor market outcomes and are robust to several specifications.

The study also represents an important contribution to the policy discussion about the costs and benefits of expanding internet access. First, by showing that mobile broadband coverage can in fact reduce poverty and improve consumer welfare, the results provide important evidence that policy makers can use when considering the cost-benefit ratio of public policies that seek to achieve universal internet access. Second, the fact that the increase in consumption occurs mostly through improvements in labor market outcomes—particularly among women—highlights the importance of complementary policies to remove barriers to job creation, particularly for more vulnerable groups. Finally, the study highlights the importance of data collection efforts to better understand the potential benefits of digital infrastructure investments in developing countries.

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Tables

Table 1: Descriptive statistics from Nigeria GHS

Household-level

	Obs.	Mean	Std. Dev.	Min.	Max.
Total consumption (Naira)	13,732	103,350	140,576	7,225	6,968,769
Total food consumption (Naira)	13,732	69,340	119,846	3,539	6,944,891
Total non-food consumption (Naira)	13,732	34,010	52,246	650	1,771,154
Poor US$ 1.90	13,732	0.3423	0.4745	0	1
Poor US$ 3.20	13,732	0.6335	0.4819	0	1
Access to medium or strong 3 or 4G	13,732	0.5054	0.5000	0	1
Access for one year or more to 3, or 4G	13,732	0.3699	0.4828	0	1
Access for two years or more to 3, or 4G	13,732	0.2820	0.4500	0	1
Access for three years or more to 3, or 4G	13,732	0.2229	0.4162	0	1
Access to electricity	13,732	0.4678	0.4990	0	1
Number of household members	13,732	5.7250	3.1848	1	31
Housing ownership	13,732	0.7296	0.4442	0	1
Wealth index	13,732	0.1766	1.8824	-2.3963	4.3433

Individual-level (aged above 15 and below 65 years)

	Obs.	Mean	Std. Dev.	Min.	Max.
Labor force participation	40,636	0.6185	0.4858	0	1
Work outside household	40,630	0.0953	0.2937	0	1
Work on household farm	40,608	0.2942	0.4557	0	1
Work in own business	40,621	0.2993	0.4579	0	1
Access to medium or strong 3 or 4G	40,636	0.4876	0.4999	0	1
Access for one year or more to 3, or 4G	40,636	0.3574	0.4792	0	1
Access for two years or more to 3, or 4G	40,636	0.2715	0.4448	0	1
Access for three years or more to 3, or 4G	40,636	0.2146	0.4105	0	1
Access to electricity	40,636	0.4677	0.4990	0	1
Number of household members	40,636	7.1900	3.5107	1	31

Table 2: Signal strength thresholds

Radio technology	Medium Signal strength	Strong Signal strength
2G	-85 dBm	-73 dBm
3G	-91 dBm	-83 dBm
4G	-105 dBm	-95 dBm

Table 3: Impact of 3G/4G access on total consumption (fixed effects models)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Access to:								
Medium or strong 3G/4G	0.015				0.006			
	(0.023)				(0.022)			
Medium or strong 3G/4G		0.071***				0.058**		
for one year or more		(0.024)				(0.023)		
Medium or strong 3G/4G			0.090***				0.079***	
for two years or more			(0.023)				0.022	
Medium or strong 3G/4G				0.111***				0.092***
for three years or more				(0.025)				(0.023)
Additional control variables	No	No	No	No	Yes	Yes	Yes	Yes
# of observations	13,732	13,732	13,732	13,732	13,732	13,732	13,732	13,732
R-squared	0.002	0.004	0.006	0.008	0.083	0.085	0.087	0.087
Number of individuals	5,495	5,495	5,495	5,495	5,495	5,495	5,495	5,495
F statistics	1.505	3.585	5.054	6.301	70.74	71.67	73.26	74.01

Notes: Standard errors reported in parentheses are clustered by LGAs. Additional controls include access to electricity, ownership of dwelling, household size, and a wealth index although the coefficients for these variables are not reported to save space. *** p<0.01, ** p<0.05, * p<0.1.

Table 4: Impact of 3G/4G access on food consumption (fixed effects models)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Access to:								
Medium or strong 3G/4G	0.014				0.005			
	(0.026)				(0.025)			
Medium or strong 3G/4G		0.073***				0.062**		
for one year		(0.028)				(0.026)		
Medium or strong 3G/4G			0.085***				0.078***	
for two years or more			(0.027)				(0.025)	
Medium or strong 3G/4G				0.104***				0.089***
for three years or more				(0.028)				(0.028)
Additional control variables	No	No	No	No	Yes	Yes	Yes	Yes
# of observations	13,732	13,732	13,732	13,732	13,732	13,732	13,732	13,732
R-squared	0.003	0.005	0.006	0.007	0.071	0.072	0.073	0.074
Number of individuals	5,495	5,495	5,495	5,495	5,495	5,495	5,495	5,495
F statistics	2.345	4.269	5.095	6.019	60.35	60.94	61.94	63.21

Notes: Standard errors reported in parentheses are clustered by LGAs. Additional controls include access to electricity, ownership of dwelling, household size, and a wealth index although the coefficients for these variables are not reported to save space. *** p<0.01, ** p<0.05, * p<0.1.

Table 5: Impact of 3G/4G access on non-food consumption (fixed effects models)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Access to:								
Medium or strong 3G/4G	0.030				0.019			
	(0.025)				(0.024)			
Medium or strong 3G/4G		0.080***				0.063**		
for one year		(0.026)				(0.025)		
Medium or strong 3G/4G			0.081***				0.061**	
for two years or more			(0.025)				(0.024)	
Medium or strong 3G/4G				0.099***				0.069***
for three years or more				(0.027)				(0.026)
Additional control variables	No	No	No	No	Yes	Yes	Yes	Yes
# of observations	13,732	13,732	13,732	13,732	13,732	13,732	13,732	13,732
R-squared	0.005	0.007	0.008	0.009	0.085	0.086	0.086	0.087
Number of individuals	5,495	5,495	5,495	5,495	5,495	5,495	5,495	5,495
F statistics	5.164	6.710	6.966	8.006	64.21	64.72	64.34	64.84

Notes: Standard errors reported in parentheses are clustered by LGAs. Additional controls include access to electricity, ownership of dwelling, household size, and a wealth index although the coefficients for these variables are not reported to save space. *** p<0.01, ** p<0.05, * p<0.1.

Table 6: Impact of 3G/4G access on poverty status ($1.90 poverty line) (fixed effects models)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Access to:								
Medium or strong 3G/4G	-0.026				-0.021			
	(0.017)				(0.017)			
Medium or strong 3G/4G for one year		-0.050***				-0.043***		
		(0.017)				(0.016)		
Medium or strong 3G/4G for two years or more			-0.075***				-0.069***	
			(0.016)				(0.015)	
Medium or strong 3G/4G for three years or more				-0.079***				-0.068***
				(0.017)				(0.017)
Additional control variables	No	No	No	No	Yes	Yes	Yes	Yes
# of observations	13,732	13,732	13,732	13,732	13,732	13,732	13,732	13,732
R-squared	0.003	0.004	0.007	0.007	0.042	0.043	0.046	0.045
Number of individuals	5,495	5,495	5,495	5,495	5,495	5,495	5,495	5,495
F statistics	2.864	4.329	7.453	7.005	35.20	36.10	38.19	37.16

Notes: Standard errors reported in parentheses are clustered by LGAs. Additional controls include access to electricity, ownership of dwelling, household size, and a wealth index although the coefficients for these variables are not reported to save space. *** p<0.01, ** p<0.05, * p<0.1.

Table 7: Impact of 3G/4G access on poverty status ($3.20 poverty line) (fixed effects models)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Access to:								
Medium or strong 3G/4G	-0.022				-0.017			
	(0.015)				(0.014)			
Medium or strong 3G/4G for one year		-0.032**				-0.026		
		(0.016)				(0.016)		
Medium or strong 3G/4G for two years or more			-0.026				-0.020	
			(0.016)				(0.016)	
Medium or strong 3G/4G for three years or more				-0.036**				-0.026
				(0.017)				(0.016)
Additional control variables	No	No	No	No	Yes	Yes	Yes	Yes
# of observations	13,732	13,732	13,732	13,732	13,732	13,732	13,732	13,732
R-squared	0.006	0.007	0.006	0.007	0.043	0.043	0.043	0.043
Number of individuals	5,495	5,495	5,495	5,495	5,495	5,495	5,495	5,495
F statistics	7.879	9.306	9.180	8.361	32.14	33.52	32.70	32.17

Notes: Standard errors reported in parentheses are clustered by LGAs. Additional controls include access to electricity, ownership of dwelling, household size, and a wealth index although the coefficients for these variables are not reported to save space. *** p<0.01, ** p<0.05, * p<0.1.

Table 8: Impact of 3G/4G access on labor participation (fixed effects models)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Access to:								
Medium or strong 3G/4G	-0.008				-0.009			
	(0.012)				(0.012)			
Medium or strong 3G/4G for one year		0.005				0.004		
		(0.012)				(0.012)		
Medium or strong 3G/4G for two years or more			0.027**				0.026**	
			(0.011)				(0.011)	
Medium or strong 3G/4G for three years or more				0.034***				0.033***
				(0.012)				(0.011)
Additional control variables	No	No	No	No	Yes	Yes	Yes	Yes
# of observations	40,636	40,636	40,636	40,636	40,636	40,636	40,636	40,636
R-squared	0.007	0.007	0.008	0.008	0.007	0.007	0.008	0.008
Number of individuals	19,194	19,194	19,194	19,194	19,194	19,194	19,194	19,194
F statistics	11.98	12.09	15.34	17.66	6.944	6.854	8.278	9.566

Notes: Standard errors reported in parentheses are clustered by LGAs. Additional controls include access to electricity, ownership of dwelling, household size, and a wealth index although the coefficients for these variables are not reported to save space. *** p<0.01, ** p<0.05, * p<0.1.

Table 9: Impact of 3G/4G access on farm self employment (fixed effects models)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Access to:								
Medium or strong 3G/4G	-0.008				-0.007			
	(0.013)				(0.013)			
Medium or strong 3G/4G for one year		-0.005				-0.004		
		(0.014)				(0.014)		
Medium or strong 3G/4G for two years or more			0.013				0.014	
			(0.013)				(0.013)	
Medium or strong 3G/4G for three years or more				0.012				0.014
				(0.013)				(0.013)
Additional control variables	No	No	No	No	Yes	Yes	Yes	Yes
# of observations	40,608	40,608	40,608	40,608	40,608	40,608	40,608	40,608
R-squared	0.002	0.001	0.002	0.002	0.003	0.003	0.003	0.003
Number of individuals	19,182	19,182	19,182	19,182	19,182	19,182	19,182	19,182
F statistics	2.098	2.104	2.132	2.099	2.964	2.960	3.073	3.009

Notes: Standard errors reported in parentheses are clustered by LGAs. Additional controls include access to electricity, ownership of dwelling, household size, and a wealth index although the coefficients for these variables are not reported to save space. *** p<0.01, ** p<0.05, * p<0.1.

Table 10: Impact of 3G/4G access on wage/salaried employment (fixed effects models)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Access to:								
Medium or strong 3G/4G	0.005				0.005			
	(0.006)				(0.006)			
Medium or strong 3G/4G for one year		0.001				0.001		
		(0.006)				(0.006)		
Medium or strong 3G/4G for two years or more			0.005				0.004	
			(0.006)				(0.006)	
Medium or strong 3G/4G for three years or more				0.015***				0.014**
				(0.006)				(0.006)
Additional control variables	No	No	No	No	Yes	Yes	Yes	Yes
# of observations	40,630	40,630	40,630	40,630	40,630	40,630	40,630	40,630
R-squared	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.001
Number of individuals	19,193	19,193	19,193	19,193	19,193	19,193	19,193	19,193
F statistics	1.624	1.390	1.513	3.045	1.598	1.568	1.609	2.297

Notes: Standard errors reported in parentheses are clustered by LGAs. Additional controls include access to electricity, ownership of dwelling, household size, and a wealth index although the coefficients for these variables are not reported to save space. *** p<0.01, ** p<0.05, * p<0.1.

Table 11: Impact of 3G/4G access on non-farm self employment (fixed effects models)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Access to:								
Medium or strong 3G/4G	0.005				0.005			
	(0.010)				(0.010)			
Medium or strong 3G/4G for one year		0.004				0.004		
		(0.009)				(0.008)		
Medium or strong 3G/4G for two years or more			0.004				0.004	
			(0.008)				(0.009)	
Medium or strong 3G/4G for three years or more				0.005				0.005
				(0.009)				(0.009)
Additional control variables	No	No	No	No	Yes	Yes	Yes	Yes
# of observations	40,621	40,621	40,621	40,621	40,621	40,621	40,621	40,621
R-squared	0.002	0.002	0.002	0.002	0.003	0.003	0.003	0.003
Number of individuals	19,191	19,191	19,191	19,191	19,191	19,191	19,191	19,191
F statistics	5.872	6.347	6.081	6.040	3.297	3.569	3.422	3.412

Notes: Standard errors reported in parentheses are clustered by LGAs. Additional controls include access to electricity, ownership of dwelling, household size, and a wealth index although the coefficients for these variables are not reported to save space. *** p<0.01, ** p<0.05, * p<0.1.

Table 12: Impact of 3G/4G access on food prices (fixed effects models)

Food products	Rice	Palm oil	Beef	White beans	Groundnut oil
Access to:					
Medium or strong 3G/4G	-0.017	0.030	0.015	0.029	0.056
	(0.040)	(0.052)	(0.039)	(0.028)	(0.059)
Medium or strong 3G/4G	-0.024	-0.043	-0.002	0.019	0.070
for one year	(0.061)	(0.063)	(0.054)	(0.032)	(0.081)
Medium or strong 3G/4G	-0.063	-0.088	0.047	-0.042	-0.110
for two years or more	(0.098)	(0.071)	(0.031)	(0.041)	(0.076)
Medium or strong 3G/4G	0.058	-0.034	0.032	-0.018	-0.044
for three years or more	(0.057)	(0.048)	(0.035)	(0.032)	(0.055)
# of observations	1,013	1,243	1,215	1,162	1,160

Notes: Standard errors reported in parentheses are clustered by LGAs. Additional controls include access to electricity, ownership of dwelling, household size, and a wealth index although the coefficients for these variables are not reported to save space. *** p<0.01, ** p<0.05, * p<0.1.

Table 13: Impact of 3G/4G access on total consumption by group (fixed effects models)

	Female Headed		Consumption		Region	
	No	Yes	Low	High	South	North
Access to:						
Medium or strong 3G/4G	0.013	-0.025	0.043	-0.034	0.026	0.011
	(0.024)	(0.035)	(0.027)	(0.027)	(0.028)	(0.029)
Medium or strong 3G/4G	0.067***	0.010	0.094***	0.057*	0.060**	0.040
for one year	(0.025)	(0.034)	(0.028)	(0.031)	(0.028)	(0.030)
Medium or strong 3G/4G	0.089***	0.010	0.153***	0.119***	0.053*	0.049
for two years or more	(0.024)	(0.035)	(0.027)	(0.028)	(0.027)	(0.031)
Medium or strong 3G/4G	0.093***	0.034	0.188***	0.122***	0.027	0.040
for three years or more	(0.025)	(0.037)	(0.030)	(0.027)	(0.027)	(0.032)
# of observations	10,772	2,959	7,246	6,297	6,747	6,985
	Age Household Head		Locality Type		Education	
	Under 50	50 or older	Rural	Urban	Primary or more	Less than primary
Access to:						
Medium or strong 3G/4G	-0.013	0.024	0.015	0.004	-0.004	0.041
	(0.029)	(0.025)	(0.025)	(0.041)	(0.025)	(0.045)
Medium or strong 3G/4G	0.051*	0.053**	0.069**	0.023	0.069***	0.035
for one year	(0.030)	(0.027)	(0.028)	(0.038)	(0.025)	(0.043)
Medium or strong 3G/4G	0.087***	0.055**	0.115***	-0.007	0.088***	0.021
for two years or more	(0.027)	(0.026)	(0.028)	(0.035)	(0.024)	(0.045)
Medium or strong 3G/4G	0.084***	0.078***	0.169***	-0.062*	0.081***	0.095**
for three years or more	(0.028)	(0.029)	(0.028)	(0.038)	(0.025)	(0.048)
# of observations	6,738	6,574	9,442	4,290	8,645	2,076

	Literacy		Children under 3	
	Illiterate	Literate	No	Yes
Access to:				
Medium or strong 3G/4G	0.033	-0.012	-0.010	0.019
	(0.035)	(0.027)	(0.026)	(0.028)
Medium or strong 3G/4G	0.047	0.060**	0.055**	0.055**
for one year	(0.036)	(0.027)	(0.027)	(0.027)
Medium or strong 3G/4G	0.090***	0.063**	0.062**	0.085***
for two years or more	(0.035)	(0.026)	(0.026)	(0.027)
Medium or strong 3G/4G	0.151***	0.064**	0.090***	0.078***
for three years or more	(0.039)	(0.026)	(0.027)	(0.029)
# of observations	4,976	8,587	6,423	7,309

Notes: Standard errors reported in parentheses are clustered by LGAs. *** p<0.01, ** p<0.05, * p<0.1.

Table 14: Impact of 3G/4G access on food consumption by group (fixed effects models)

	Female Headed		Consumption		Region	
	No	Yes	Low	High	South	North
Access to:						
Medium or strong 3G/4G	0.007	-0.000	0.042	-0.033	0.043	0.004
	(0.027)	(0.042)	(0.031)	(0.032)	(0.032)	(0.033)
Medium or strong 3G/4G	0.070**	0.019	0.102***	0.061	0.073**	0.044
for one year	(0.027)	(0.041)	(0.031)	(0.037)	(0.032)	(0.033)
Medium or strong 3G/4G	0.090***	-0.005	0.172***	0.105***	0.056*	0.054*
for two years or more	(0.027)	(0.040)	(0.030)	(0.032)	(0.032)	(0.032)
Medium or strong 3G/4G	0.092***	0.009	0.208***	0.104***	0.019	0.034
for three years or more	(0.028)	(0.041)	(0.033)	(0.031)	(0.031)	(0.033)
# of observations	10,772	2,959	7,246	6,297	6,747	6,985
	Age Household Head		Locality Type		Education	
	Under 50	50 or older	Rural	Urban	Primary or more	Less than primary
Access to:						
Medium or strong 3G/4G	-0.021	0.035	0.009	0.026	-0.006	0.036
	(0.033)	(0.029)	(0.029)	(0.048)	(0.029)	(0.052)
Medium or strong 3G/4G	0.061*	0.056*	0.077**	0.021	0.080***	0.034
for one year	(0.034)	(0.031)	(0.032)	(0.044)	(0.030)	(0.048)
Medium or strong 3G/4G	0.090***	0.052*	0.129***	-0.044	0.090***	0.014
for two years or more	(0.030)	(0.031)	(0.033)	(0.042)	(0.028)	(0.051)
Medium or strong 3G/4G	0.081***	0.076**	0.186***	-0.111**	0.078***	0.092*
for three years or more	(0.031)	(0.034)	(0.032)	(0.043)	(0.030)	(0.053)
# of observations	6,738	6,574	9,442	4,290	8,645	2,076

	Literacy		Children under 3	
	Illiterate	Literate	No	Yes
Access to:				
Medium or strong 3G/4G	0.031	-0.015	0.003	0.008
	(0.041)	(0.032)	(0.030)	(0.032)
Medium or strong 3G/4G	0.043	0.066**	0.056*	0.063**
for one year	(0.042)	(0.031)	(0.031)	(0.031)
Medium or strong 3G/4G	0.100**	0.056*	0.038	0.107***
for two years or more	(0.040)	(0.031)	(0.030)	(0.030)
Medium or strong 3G/4G	0.161***	0.055*	0.069**	0.092***
for three years or more	(0.043)	(0.032)	(0.031)	(0.032)
# of observations	4,976	8,587	6,423	7,309

Notes: Standard errors reported in parentheses are clustered by LGAs. *** p<0.01, ** p<0.05, * p<0.1.

Table 15: Impact of 3G/4G access on non-food consumption by group (fixed effects models)

	Female Headed		Consumption		Region	
	No	Yes	Low	High	South	North
Access to:						
Medium or strong 3G/4G	0.043	-0.088**	0.061**	-0.027	-0.009	0.047
	(0.027)	(0.041)	(0.029)	(0.032)	(0.034)	(0.033)
Medium or strong 3G/4G	0.072***	0.013	0.080***	0.070**	0.050*	0.036
for one year	(0.028)	(0.039)	(0.031)	(0.032)	(0.030)	(0.039)
Medium or strong 3G/4G	0.066**	0.023	0.103***	0.105***	0.022	0.021
for two years or more	(0.027)	(0.042)	(0.031)	(0.030)	(0.027)	(0.043)
Medium or strong 3G/4G	0.070**	0.040	0.130***	0.105***	0.009	0.025
for three years or more	(0.028)	(0.044)	(0.034)	(0.030)	(0.028)	(0.045)
# of observations	10,772	2,959	7,246	6,297	6,747	6,985

	Age Household Head		Locality Type		Education	
	Under 50	50 or older	Rural	Urban	Primary or more	Less than primary
Access to:						
Medium or strong 3G/4G	0.017	0.013	0.035	-0.014	0.011	0.077
	(0.031)	(0.030)	(0.028)	(0.045)	(0.028)	(0.047)
Medium or strong 3G/4G	0.046	0.055*	0.070**	0.038	0.055**	0.030
for one year	(0.031)	(0.030)	(0.029)	(0.041)	(0.027)	(0.047)
Medium or strong 3G/4G	0.064**	0.040	0.076**	0.052	0.050*	0.043
for two years or more	(0.030)	(0.028)	(0.030)	(0.037)	(0.025)	(0.047)
Medium or strong 3G/4G	0.065**	0.048	0.117***	0.011	0.047*	0.093*
for three years or more	(0.032)	(0.031)	(0.033)	(0.039)	(0.026)	(0.054)
# of observations	6,738	6,574	9,442	4,290	8,645	2,076

	Literacy		Children under 3	
	Illiterate	Literate	No	Yes
Access to:				
Medium or strong 3G/4G	0.050	0.007	-0.011	0.044
	(0.036)	(0.028)	(0.029)	(0.030)
Medium or strong 3G/4G	0.087**	0.056**	0.065**	0.058*
for one year	(0.038)	(0.028)	(0.030)	(0.031)
Medium or strong 3G/4G	0.077*	0.050*	0.070**	0.046
for two years or more	(0.039)	(0.027)	(0.028)	(0.031)
Medium or strong 3G/4G	0.110**	0.045	0.083***	0.047
for three years or more	(0.044)	(0.028)	(0.030)	(0.033)
# of observations	4,976	8,587	6,423	7,309

Notes: Standard errors reported in parentheses are clustered by LGAs. *** p<0.01, ** p<0.05, * p<0.1.

Table 16: Impact of 3G/4G access on poverty status ($1.90 poverty line) by group (fixed effects models)

	Female Headed		Consumption		Region	
	No	Yes	Low	High	South	North
Access to:						
Medium or strong 3G/4G	-0.019	-0.031	-0.020	-0.017	-0.032	-0.022
	(0.018)	(0.027)	(0.024)	(0.016)	(0.020)	(0.024)
Medium or strong 3G/4G	-0.050***	-0.003	-0.065***	-0.036**	-0.030*	-0.036
for one year	(0.017)	(0.024)	(0.024)	(0.016)	(0.018)	(0.025)
Medium or strong 3G/4G	-0.077***	-0.018	-0.117***	-0.086***	-0.051***	-0.036
for two years or more	(0.017)	(0.024)	(0.024)	(0.016)	(0.017)	(0.029)
Medium or strong 3G/4G	-0.076***	-0.003	-0.125***	-0.090***	-0.031	-0.020
for three years or more	(0.018)	(0.027)	(0.026)	(0.016)	(0.020)	(0.031)
# of observations	10,772	2,959	7,246	6,297	6,747	6,985

	Age Household Head		Locality Type		Education	
	Under 50	50 or older	Rural	Urban	Primary or more	Less than primary
Access to:						
Medium or strong 3G/4G	-0.009	-0.030	-0.028	-0.011	-0.028	-0.010
	(0.021)	(0.021)	(0.021)	(0.027)	(0.018)	(0.042)
Medium or strong 3G/4G	-0.058***	-0.015	-0.052**	-0.017	-0.059***	-0.010
for one year	(0.022)	(0.019)	(0.021)	(0.021)	(0.017)	(0.039)
Medium or strong 3G/4G	-0.095***	-0.028	-0.080***	-0.034*	-0.087***	-0.009
for two years or more	(0.021)	(0.019)	(0.021)	(0.020)	(0.017)	(0.037)
Medium or strong 3G/4G	-0.093***	-0.027	-0.103***	0.006	-0.084***	-0.028
for three years or more	(0.021)	(0.021)	(0.024)	(0.022)	(0.018)	(0.040)
# of observations	6,738	6,574	9,442	4,290	8,645	2,076

	Literacy		Children under 3	
	Illiterate	Literate	No	Yes
Access to:				
Medium or strong 3G/4G	-0.026	-0.030	-0.022	-0.020
	(0.029)	(0.019)	(0.020)	(0.022)
Medium or strong 3G/4G	-0.048*	-0.045**	-0.025	-0.053**
for one year	(0.028)	(0.018)	(0.017)	(0.022)
Medium or strong 3G/4G	-0.058**	-0.068***	-0.032*	-0.095***
for two years or more	(0.028)	(0.018)	(0.016)	(0.023)
Medium or strong 3G/4G	-0.060**	-0.068***	-0.032*	-0.093***
for three years or more	(0.030)	(0.018)	(0.018)	(0.023)
# of observations	4,976	8,587	6,423	7,309

Notes: Standard errors reported in parentheses are clustered by LGAs. *** p<0.01, ** p<0.05, * p<0.1.

Table 17: Impact of 3G/4G access on poverty status ($3.20 poverty line) by group (fixed effects models)

	Female Headed		Consumption		Region	
	No	Yes	Low	High	South	North
Access to:						
Medium or strong 3G/4G	-0.013	-0.034	-0.031**	-0.000	-0.044**	-0.002
	(0.016)	(0.033)	(0.014)	(0.024)	(0.021)	(0.018)
Medium or strong 3G/4G	-0.027	-0.010	-0.065***	-0.024	-0.035	-0.001
for one year	(0.017)	(0.032)	(0.016)	(0.026)	(0.023)	(0.019)
Medium or strong 3G/4G	-0.026	0.029	-0.090***	-0.069***	-0.003	0.000
for two years or more	(0.017)	(0.031)	(0.017)	(0.024)	(0.023)	(0.019)
Medium or strong 3G/4G	-0.023	0.000	-0.109***	-0.083***	0.001	0.016
for three years or more	(0.016)	(0.033)	(0.020)	(0.023)	(0.023)	(0.021)
# of observations	10,772	2,959	7,246	6,297	6,747	6,985
	Age Household Head		Locality Type		Education	
	Under 50	50 or older	Rural	Urban	Primary or more	Less than primary
Access to:						
Medium or strong 3G/4G	-0.004	-0.030	-0.011	-0.028	-0.020	-0.022
	(0.020)	(0.019)	(0.016)	(0.030)	(0.018)	(0.031)
Medium or strong 3G/4G	-0.004	-0.035	-0.022	-0.029	-0.029	-0.036
for one year	(0.021)	(0.022)	(0.020)	(0.027)	(0.018)	(0.033)
Medium or strong 3G/4G	-0.010	-0.016	-0.036*	-0.007	-0.015	-0.020
for two years or more	(0.019)	(0.021)	(0.020)	(0.027)	(0.018)	(0.032)
Medium or strong 3G/4G	-0.005	-0.030	-0.076***	0.039	-0.008	-0.089***
for three years or more	(0.019)	(0.023)	(0.019)	(0.027)	(0.018)	(0.030)
# of observations	6,738	6,574	9,442	4,290	8,645	2,076
	Literacy		Children under 3			
	Illiterate	Literate	No	Yes		
Access to:						
Medium or strong 3G/4G	-0.022	-0.003	-0.019	-0.015		
	(0.024)	(0.019)	(0.020)	(0.018)		
Medium or strong 3G/4G	-0.026	-0.025	-0.035*	-0.014		
for one year	(0.026)	(0.019)	(0.020)	(0.019)		
Medium or strong 3G/4G	-0.036	-0.013	-0.026	-0.009		
for two years or more	(0.025)	(0.019)	(0.020)	(0.019)		
Medium or strong 3G/4G	-0.083***	-0.013	-0.039*	-0.006		
for three years or more	(0.027)	(0.019)	(0.021)	(0.019)		
# of observations	4,976	8,587	6,423	7,309		

Notes: Standard errors reported in parentheses are clustered by LGAs. *** p<0.01, ** p<0.05, * p<0.1.

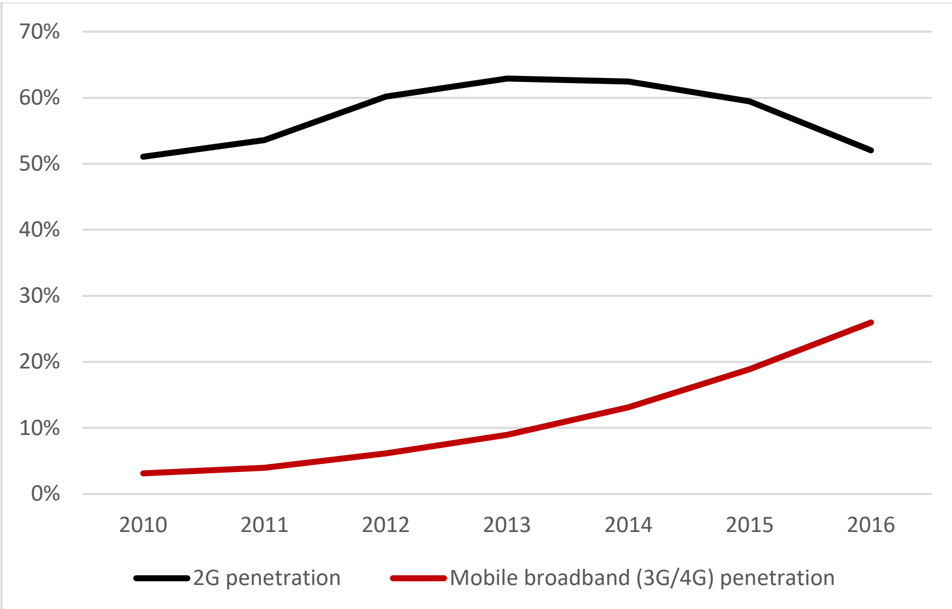
Table 18: Tests on pre-trends

	Total Consumption		Food Consumption		Non-food Consumption	
	Waves 2 & 3	Pre-Trend	Waves 2 & 3	Pre-Trend	Waves 2 & 3	Pre-Trend
Access to:						
Medium or strong 3G/4G	-0.054	0.028	-0.075*	0.043	-0.013	0.023
	(0.036)	(0.038)	(0.043)	(0.044)	(0.034)	(0.039)
Medium or strong 3G/4G	0.048	0.027	0.046	0.043	0.044	0.036
for one year	(0.033)	(0.029)	(0.038)	(0.034)	(0.031)	(0.031)
Medium or strong 3G/4G	0.099***	0.008	0.120***	0.011	0.039	0.032
for two years or more	(0.033)	(0.030)	(0.038)	(0.036)	(0.032)	(0.032)
Medium or strong 3G/4G	0.152***	-0.023	0.169***	-0.015	0.104***	-0.012
for three years or more	(0.032)	(0.030)	(0.037)	(0.035)	(0.031)	(0.030)
# of observations	9,022	8,580	9,022	8,580	9,022	8,580
	Poverty $1.90		Poverty $3.20		Labor force participation	
	Waves 2 & 3	Pre-Trend	Waves 2 & 3	Pre-Trend	Waves 2 & 3	Pre-Trend
Access to:						
Medium or strong 3G/4G	0.004	0.010	0.015	-0.017	-0.021	-0.015
	(0.027)	(0.029)	(0.022)	(0.024)	(0.019)	(0.017)
Medium or strong 3G/4G	-0.037	-0.031	-0.007	-0.017	-0.001	-0.004
for one year	(0.023)	(0.022)	(0.020)	(0.020)	(0.016)	(0.015)
Medium or strong 3G/4G	-0.072***	-0.013	-0.042**	-0.010	0.016	-0.003
for two years or more	(0.023)	(0.023)	(0.021)	(0.020)	(0.016)	(0.015)
Medium or strong 3G/4G	-0.091***	0.001	-0.076***	0.016	0.021	0.005
for three years or more	(0.022)	(0.022)	(0.021)	(0.021)	(0.015)	(0.014)
# of observations	9,022	8,580	9,022	8,580	27,349	25,445
	Farm self-employment		Wage/salaried employment		Non-farm self-employment	
	Waves 2 & 3	Pre-Trend	Waves 2 & 3	Pre-Trend	Waves 2 & 3	Pre-Trend
Access to:						
Medium or strong 3G/4G	-0.011	0.004	-0.006	-0.010	0.008	-0.018
	(0.023)	(0.020)	(0.006)	(0.009)	(0.014)	(0.014)
Medium or strong 3G/4G	0.010	-0.004	-0.007	0.005	-0.005	0.014
for one year	(0.019)	(0.016)	(0.006)	(0.008)	(0.010)	(0.012)
Medium or strong 3G/4G	0.020	-0.008	-0.009	0.012	-0.003	0.012
for two years or more	(0.018)	(0.016)	(0.007)	(0.008)	(0.011)	(0.013)
Medium or strong 3G/4G	0.013	-0.011	0.003	0.006	0.003	0.012
for three years or more	(0.018)	(0.015)	(0.007)	(0.008)	(0.010)	(0.012)
# of observations	27,348	25,431	27,348	25,439	27,347	25,433

Notes: Standard errors reported in parentheses are clustered by LGAs. *** p<0.01, ** p<0.05, * p<0.1.

Figures

Figure 1: Mobile penetration in Nigeria by technology, based on connections



Source: GSMA Intelligence. Penetration is calculated by dividing the total number of 2G and 3G/4G connections by total population.

Figure 2: Area covered with signal strength

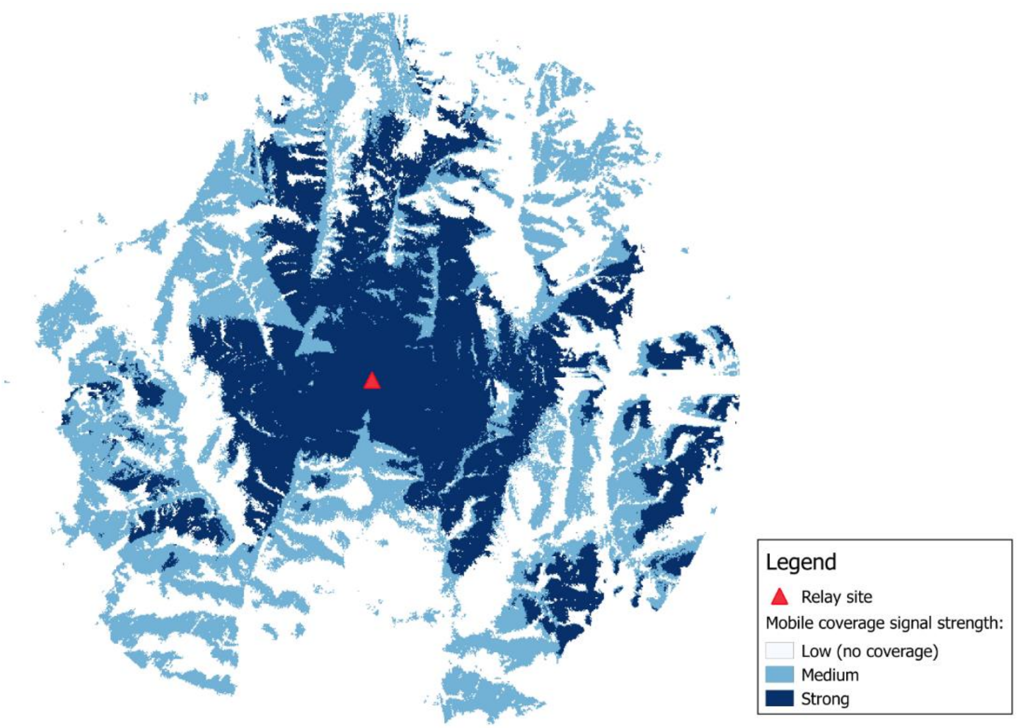


Figure 3: 3G coverage in 2010, 2012, and 2015

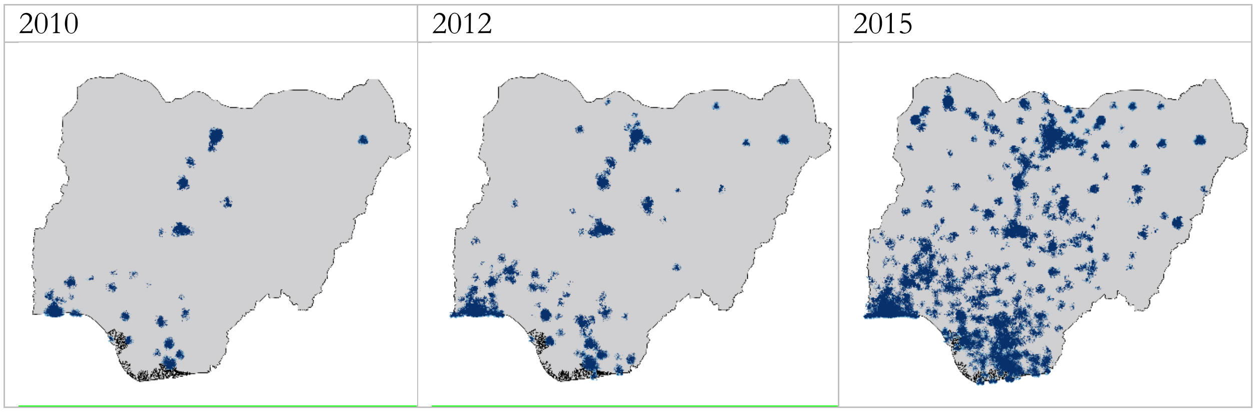
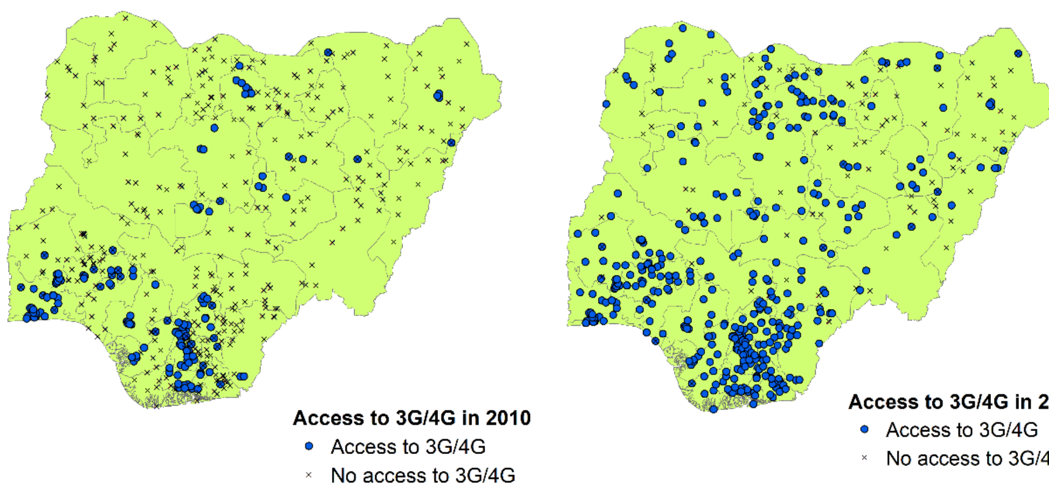


Figure 4: 3G coverage for surveyed locations in 2010 and 2016



Notes: This graph shows the locations of enumeration areas where at least one household has access to 3G/4G technology.

Appendix 1: Additional results

In this appendix we present some additional results omitted from the main text. All results are shown in this appendix are for the specification with all control variables. The first exercise consists of replacing the different binary treatments with a continuous one that measures the number of months a household has been covered by a 3/4G signal. All results on consumption and poverty status are statistically significant at the one-percent or five-percent level. One additional month of coverage increases total, food, and non-food consumption by 0.3%, 0.4%, and 0.2%, respectively. The probability of falling below the US$ 1.90 poverty line falls by 0.3, and below the US$ 3.20 poverty line by 0.1 percentage points. At the individual level, the probability of being in the labor force increase by 0.1 percentage points. All these results confirm our other findings.

Next, in Table A 2 we show results for an estimation in first differences, instead of fixed effects (FE). FE estimation is preferred in most cases, since for more than two time periods any bias induced by a possible non-contemporary correlation of the error term with the treatment is reduced (and would asymptotically go to zero as the number of time periods approaches infinity). Another advantage of the FE estimates is that it drops fewer observations in the case of an unbalanced panel. In our case, if an observation has a missing value in wave two, neither the differences between waves one and two, nor between waves two and three could be formed. However, this observation would still enter the FE estimation in waves one and two. Because of differencing, for a balanced panel with three time periods, the total number of reported observations in the FD estimation would be two-thirds of the number reported in FE. Comparing the number of observations in Table A 2 to our main results, we lose close to 7.5% of our observations in the FD approach. This is another important reason to prefer FE. The results are mostly in line with the FE ones, albeit with a smaller coefficient. One important difference is that for the first treatment, coverage for any amount of time, the FD estimates are negative. It is important to point out that if the treatment effects vary with time, FE and FD do not measure the same thing. FE provides an estimate of the average effect of being covered, while FD estimates the short-term effect of receiving coverage (if the treatment effect was constant, this difference would not matter). So, if the more immediate effect of receiving coverage is negative, followed by a longer-term positive effect, FD would pick up the former, whereas FE would average over the two. The FD results are weaker and we find statistical significance mostly only for three years or more of coverage.

In Table A 3, we show results for all the control variables which are omitted from the tables in the main text for brevity. In Table A4-A7, we show results for labor outcome variables by groups.

Table A 1: The impact of 3G/4G access measured in months on welfare and labor outcomes

	Tot Cons	Food Cons	Non-food Cons	Pov $1.90	Pov $3.20	Lab Force	Farm self-employment	Wage/salaried employment	Non-farm self-employment
Access to:									
Months covered 3 or 4G	0.003***	0.004***	0.002***	-0.003***	-0.001**	0.001***	0.000	0.000***	0.000
	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
# of observations	13,732	13,732	13,732	13,732	13,732	40,636	40,608	40,630	40,621
R-squared	0.092	0.079	0.088	0.049	0.044	0.009	0.003	0.002	0.003
Number of individuals	5,495	5,495	5,495	5,495	5,495	19,194	19,182	19,193	19,191
F statistics	77.67	68.36	64.96	40.15	33.16	10.50	2.985	2.943	3.538

Notes: Standard errors reported in parentheses are clustered by LGAs. All these regressions include the additional set of controls (e.g., access to electricity, ownership of dwelling, household size, and a wealth index) although the coefficients for these variables are not reported to save space. *** p<0.01, ** p<0.05, * p<0.1.

Table A 2: The impact of 3G/4G access on welfare and labor outcomes (in first differences)

	Tot Cons	Food Cons	Non-food Cons	Pov $1.90	Pov $3.20	Lab Force	Farm self-employment	Wage/salaried employment	Non-farm self-employment
Access to:									
Medium or strong 3G/4G	-0.027	-0.034	-0.007	-0.001	0.002	-0.000	-0.003	0.006	0.008
	(0.025)	(0.031)	(0.025)	(0.019)	(0.015)	(0.012)	(0.014)	(0.005)	(0.009)
Medium or strong 3G/4G	0.020	0.019	0.025	-0.013	-0.006	0.005	-0.001	-0.002	-0.002
for one year	(0.026)	(0.031)	(0.024)	(0.018)	(0.019)	(0.011)	(0.014)	(0.006)	(0.008)
Medium or strong 3G/4G	0.031	0.023	0.024	-0.038**	-0.007	0.017	0.011	-0.002	0.001
for two years or more	(0.026)	(0.031)	(0.024)	(0.017)	(0.019)	(0.011)	(0.012)	(0.006)	(0.008)
Medium or strong 3G/4G	0.066**	0.054	0.058**	-0.055***	-0.032	0.023**	0.012	0.011*	0.004
for three years or more	(0.028)	(0.034)	(0.025)	(0.018)	(0.020)	(0.011)	(0.012)	(0.006)	(0.008)
# of observations	8,471	8,471	8,471	8,471	8,471	23,857	23,847	23,851	23,843

Notes: Standard errors reported in parentheses are clustered by LGAs. All these regressions include the additional set of controls (e.g., access to electricity, ownership of dwelling, household size, and a wealth index) although the coefficients for these variables are not reported to save space. *** p<0.01, ** p<0.05, * p<0.1.

Table A 3: Impact of 3G/4G access with additional control variables

	Total consumption				Food consumption			
Access to:								
Medium or strong 3G/4G	0.006				0.005			
	(0.022)				(0.025)			
Medium or strong 3G/4G		0.058**				0.062**		
for one year		(0.023)				(0.026)		
Medium or strong 3G/4G			0.079***				0.078***	
for two years or more			(0.022)				(0.025)	
Medium or strong 3G/4G				0.092***				0.089***
for three years or more				(0.023)				(0.026)
Control variables								
Access to electricity	0.061***	0.061***	0.062***	0.062***	0.058***	0.059***	0.060***	0.059***
	(0.016)	(0.016)	(0.016)	(0.016)	(0.018)	(0.018)	(0.018)	(0.018)
Household size	-0.099***	-0.098***	-0.098***	-0.098***	-0.106***	-0.106***	-0.106***	-0.106***
	(0.004)	(0.004)	(0.004)	(0.004)	(0.005)	(0.005)	(0.005)	(0.005)
Housing ownership	0.054***	0.053***	0.051**	0.051***	0.033	0.031	0.029	0.029
	(0.019)	(0.020)	(0.020)	(0.019)	(0.022)	(0.022)	(0.022)	(0.022)
Wealth index	0.055***	0.054***	0.053***	0.052***	0.027***	0.027***	0.025***	0.024***
	(0.008)	(0.008)	(0.008)	(0.008)	(0.009)	(0.009)	(0.008)	(0.008)
Access to	-0.031	-0.021	-0.008	-0.004	-0.090	-0.080	-0.068	-0.064
medium or strong 2G, 3G, or 4G	(0.088)	(0.087)	(0.087)	(0.088)	(0.096)	(0.095)	(0.094)	(0.095)
# of observations	13,732	13,732	13,732	13,732	13,732	13,732	13,732	13,732
R-squared	0.083	0.085	0.087	0.087	0.071	0.072	0.073	0.074
Number of individuals	5,495	5,495	5,495	5,495	5,495	5,495	5,495	5,495
F statistics	70.74	71.67	73.26	74.01	60.35	60.94	61.94	63.21

	Non-food consumption				Poverty ($1.9 poverty line)			
Access to:								
Medium or strong 3G/4G	0.019				-0.021			
	(0.024)				(0.017)			
Medium or strong 3G/4G		0.063**				-0.043***		
for one year		(0.025)				(0.016)		
Medium or strong 3G/4G			0.061**				-0.069***	
for two years or more			(0.024)				(0.015)	
Medium or strong 3G/4G				0.069***				-0.068***
for three years or more				(0.026)				(0.017)
Control variables								
Access to electricity	0.067***	0.068***	0.069***	0.068***	-0.022*	-0.023*	-0.024*	-0.023*
	(0.020)	(0.020)	(0.020)	(0.020)	(0.013)	(0.013)	(0.013)	(0.013)
Household size	-0.087***	-0.087***	-0.087***	-0.086***	0.054***	0.054***	0.054***	0.054***
	(0.005)	(0.005)	(0.005)	(0.005)	(0.003)	(0.003)	(0.003)	(0.003)
Housing ownership	0.090***	0.088***	0.087***	0.087***	-0.036**	-0.035**	-0.033**	-0.033**
	(0.022)	(0.022)	(0.022)	(0.022)	(0.014)	(0.014)	(0.014)	(0.014)
Wealth index	0.117***	0.116***	0.115***	0.115***	-0.032***	-0.031***	-0.030***	-0.030***
	(0.008)	(0.008)	(0.008)	(0.008)	(0.006)	(0.006)	(0.006)	(0.006)
Access to	0.079	0.088	0.095	0.098	0.060	0.054	0.042	0.041
medium or strong 2G, 3G, or 4G	(0.114)	(0.114)	(0.114)	(0.114)	(0.071)	(0.071)	(0.070)	(0.071)
# of observations	13,732	13,732	13,732	13,732	13,732	13,732	13,732	13,732
R-squared	0.085	0.086	0.086	0.087	0.042	0.043	0.046	0.045
Number of individuals	5,495	5,495	5,495	5,495	5,495	5,495	5,495	5,495
F statistics	64.21	64.72	64.34	64.84	35.20	36.10	38.19	37.16

(*Continued*)

	Poverty ($3.2 poverty line)				Labor force participation			
Access to:								
Medium or strong 3G/4G	-0.017				-0.009			
	(0.014)				(0.012)			
Medium or strong 3G/4G for one year		-0.026				0.004		
		(0.016)				(0.012)		
Medium or strong 3G/4G for two years or more			-0.020				0.026**	
			(0.016)				(0.011)	
Medium or strong 3G/4G for three years or more				-0.026				0.033***
				(0.016)				(0.011)
Control variables								
Access to electricity	-0.019	-0.019	-0.020	-0.020	0.011	0.011	0.011	0.011
	(0.013)	(0.013)	(0.013)	(0.013)	(0.009)	(0.010)	(0.009)	(0.009)
Household size	0.052***	0.052***	0.052***	0.052***	0.002	0.002	0.002	0.002
	(0.004)	(0.004)	(0.004)	(0.004)	(0.003)	(0.003)	(0.003)	(0.003)
Housing ownership	-0.047***	-0.047***	-0.047***	-0.047***	0.013	0.013	0.012	0.012
	(0.017)	(0.017)	(0.017)	(0.017)	(0.011)	(0.011)	(0.011)	(0.011)
Wealth index	-0.026***	-0.025***	-0.025***	-0.025***	0.007	0.007	0.006	0.006
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
Access to medium or strong 2G, 3G, or 4G	-0.014	-0.017	-0.018	-0.020	0.027	0.028	0.034	0.036
	(0.040)	(0.040)	(0.041)	(0.041)	(0.049)	(0.048)	(0.049)	(0.048)
# of observations	13,732	13,732	13,732	13,732	40,636	40,636	40,636	40,636
R-squared	0.043	0.043	0.043	0.043	0.007	0.007	0.008	0.008
Number of individuals	5,495	5,495	5,495	5,495	19,194	19,194	19,194	19,194
F statistics	32.14	33.52	32.70	32.17	6.944	6.854	8.278	9.566

	Farm self employment				Wage/salaried employment			
Access to:								
Medium or strong 3G/4G	-0.007				0.005			
	(0.013)				(0.006)			
Medium or strong 3G/4G for one year		-0.004				0.001		
		(0.014)				(0.006)		
Medium or strong 3G/4G for two years or more			0.014				0.004	
			(0.013)				(0.006)	
Medium or strong 3G/4G for three years or more				0.014				0.014**
				(0.013)				(0.006)
Control variables								
Access to electricity	0.012	0.012	0.012	0.012	-0.001	-0.001	-0.001	-0.001
	(0.010)	(0.010)	(0.010)	(0.010)	(0.007)	(0.007)	(0.006)	(0.006)
Household size	0.001	0.001	0.001	0.001	-0.001	-0.001	-0.001	-0.001
	(0.002)	(0.002)	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)
Housing ownership	0.020	0.020	0.019	0.019	0.005	0.005	0.004	0.004
	(0.013)	(0.013)	(0.013)	(0.013)	(0.007)	(0.007)	(0.007)	(0.007)
Wealth index	-0.012**	-0.012**	-0.013***	-0.013***	0.006**	0.006**	0.005**	0.005**
	(0.005)	(0.005)	(0.005)	(0.005)	(0.002)	(0.002)	(0.002)	(0.002)
Access to medium or strong 2G, 3G, or 4G	0.068	0.067	0.072	0.072	-0.021	-0.021	-0.020	-0.017
	(0.065)	(0.066)	(0.066)	(0.066)	(0.015)	(0.015)	(0.015)	(0.015)
# of observations	40,608	40,608	40,608	40,608	40,630	40,630	40,630	40,630
R-squared	0.003	0.003	0.003	0.003	0.001	0.001	0.001	0.001
Number of individuals	19,182	19,182	19,182	19,182	19,193	19,193	19,193	19,193
F statistics	2.964	2.960	3.073	3.009	1.598	1.568	1.609	2.297

(*Continued*)

	Non-farm self-employment			
Access to:				
Medium or strong 3G/4G	0.005			
	(0.010)			
Medium or strong 3G/4G for one year		0.004		
		(0.008)		
Medium or strong 3G/4G for two years or more			0.004	
			(0.009)	
Medium or strong 3G/4G for three years or more				0.005
				(0.009)
Control variables				
Access to electricity	0.003	0.003	0.003	0.003
	(0.009)	(0.009)	(0.009)	(0.009)
Household size	0.002	0.002	0.002	0.002
	(0.002)	(0.002)	(0.002)	(0.002)
Housing ownership	-0.011	-0.011	-0.011	-0.011
	(0.011)	(0.011)	(0.011)	(0.011)
Wealth index	0.003	0.003	0.003	0.003
	(0.003)	(0.003)	(0.003)	(0.003)
Access to medium or strong 2G, 3G, or 4G	0.004	0.004	0.005	0.005
	(0.043)	(0.043)	(0.043)	(0.043)
# of observations	40,621	40,621	40,621	40,621
R-squared	0.003	0.003	0.003	0.003
Number of individuals	19,191	19,191	19,191	19,191
F statistics	3.297	3.569	3.422	3.412

Notes: Standard errors reported in parentheses are clustered by LGAs. *** p<0.01, ** p<0.05, * p<0.1.

Table A 4: Impact of 3G/4G access on labor force participation by group

	Gender		Consumption		Region	
	Male	Female	Low	High	South	North
Access to:						
Medium or strong 3G/4G	0.011	-0.026*	-0.008	-0.007	-0.030**	0.011
	(0.014)	(0.015)	(0.015)	(0.015)	(0.014)	(0.018)
Medium or strong 3G/4G	0.019	-0.008	0.012	-0.004	-0.002	0.008
for one year	(0.015)	(0.014)	(0.016)	(0.014)	(0.014)	(0.019)
Medium or strong 3G/4G	0.024*	0.029**	0.035**	0.014	0.013	0.035*
for two years or more	(0.014)	(0.014)	(0.015)	(0.013)	(0.014)	(0.018)
Medium or strong 3G/4G	0.018	0.046***	0.033**	0.033**	0.021	0.036*
for three years or more	(0.015)	(0.014)	(0.016)	(0.014)	(0.014)	(0.019)
# of observations	19,170	21,466	24,008	16,019	17,663	22,973

	Age		Locality Type		Education	
	Under 30	30 or older	Rural	Urban	Primary or more	Less than primary
Access to:						
Medium or strong 3G/4G	-0.019	0.010	-0.000	-0.013	-0.014	-0.007
	(0.020)	(0.011)	(0.015)	(0.019)	(0.013)	(0.029)
Medium or strong 3G/4G	0.014	-0.000	0.012	-0.007	-0.001	0.030
for one year	(0.019)	(0.011)	(0.015)	(0.016)	(0.013)	(0.033)
Medium or strong 3G/4G	0.039**	0.012	0.028*	0.002	0.019	0.050
for two years or more	(0.018)	(0.011)	(0.015)	(0.014)	(0.012)	(0.035)
Medium or strong 3G/4G	0.046***	0.017	0.029*	0.016	0.022*	0.049
for three years or more	(0.018)	(0.011)	(0.016)	(0.015)	(0.013)	(0.036)
# of observations	19,046	18,586	28,673	11,963	28,929	4,972

	Literacy		Children under 3	
	Illiterate	Literate	No	Yes
Access to:				
Medium or strong 3G/4G	0.036*	-0.019	0.008	-0.020
	(0.021)	(0.013)	(0.017)	(0.014)
Medium or strong 3G/4G	0.022	-0.002	0.013	-0.002
for one year	(0.020)	(0.013)	(0.017)	(0.014)
Medium or strong 3G/4G	0.028	0.016	0.030**	0.022
for two years or more	(0.021)	(0.012)	(0.015)	(0.014)
Medium or strong 3G/4G	0.045**	0.014	0.042***	0.023
for three years or more	(0.022)	(0.013)	(0.016)	(0.014)
# of observations	11,721	28,164	17,799	22,837

Notes: Standard errors reported in parentheses are clustered by LGAs. All these regressions include the additional set of controls (e.g., access to electricity, ownership of dwelling, household size, and a wealth index) although the coefficients for these variables are not reported to save space. *** p<0.01, ** p<0.05, * p<0.1.

Table A 5: Impact of 3G/4G access on farm self employment by group

	Gender		Consumption		Region	
	Male	Female	Low	High	South	North
Access to:						
Medium or strong 3G/4G	-0.005	-0.009	-0.008	-0.009	0.008	-0.014
	(0.018)	(0.014)	(0.017)	(0.018)	(0.019)	(0.019)
Medium or strong 3G/4G	-0.004	-0.004	0.005	-0.019	-0.007	-0.001
for one year	(0.019)	(0.014)	(0.019)	(0.014)	(0.015)	(0.023)
Medium or strong 3G/4G	0.009	0.020	0.015	0.012	0.009	0.019
for two years or more	(0.017)	(0.013)	(0.018)	(0.014)	(0.015)	(0.022)
Medium or strong 3G/4G	-0.008	0.034**	0.010	0.020	0.011	0.011
for three years or more	(0.018)	(0.013)	(0.020)	(0.013)	(0.015)	(0.021)
# of observations	19,161	21,447	23,992	16,007	17,658	22,950

	Age		Locality Type		Education	
	Under 30	30 or older	Rural	Urban	Primary or more	Less than primary
Access to:						
Medium or strong 3G/4G	-0.007	-0.000	-0.005	-0.005	-0.004	-0.023
	(0.018)	(0.015)	(0.017)	(0.015)	(0.015)	(0.031)
Medium or strong 3G/4G	-0.004	-0.002	0.002	-0.016	-0.010	0.016
for one year	(0.018)	(0.015)	(0.018)	(0.012)	(0.014)	(0.037)
Medium or strong 3G/4G	0.009	0.021	0.025	-0.010	0.008	0.037
for two years or more	(0.016)	(0.014)	(0.019)	(0.013)	(0.013)	(0.036)
Medium or strong 3G/4G	-0.009	0.034**	0.024	-0.007	0.004	0.050
for three years or more	(0.017)	(0.014)	(0.021)	(0.013)	(0.014)	(0.038)
# of observations	19,031	18,574	28,647	11,961	28,911	4,971

	Literacy		Children under 3	
	Illiterate	Literate	No	Yes
Access to:				
Medium or strong 3G/4G	0.002	-0.004	0.009	-0.018
	(0.021)	(0.014)	(0.018)	(0.016)
Medium or strong 3G/4G	0.023	-0.009	0.002	-0.008
for one year	(0.024)	(0.013)	(0.018)	(0.017)
Medium or strong 3G/4G	0.046**	0.005	0.016	0.016
for two years or more	(0.023)	(0.013)	(0.017)	(0.015)
Medium or strong 3G/4G	0.064***	-0.008	0.017	0.014
for three years or more	(0.024)	(0.013)	(0.017)	(0.016)
# of observations	11,710	28,148	17,783	22,825

Notes: Standard errors reported in parentheses are clustered by LGAs. All these regressions include the additional set of controls (e.g., access to electricity, ownership of dwelling, household size, and a wealth index) although the coefficients for these variables are not reported to save space. *** p<0.01, ** p<0.05, * p<0.1.

Table A 6: Impact of 3G/4G access on wage/salaried employment by group

	Gender		Consumption		Region	
	Male	Female	Low	High	South	North
Access to:						
Medium or strong 3G/4G	0.007	0.002	0.001	0.010	-0.011	0.012*
	(0.008)	(0.006)	(0.006)	(0.010)	(0.009)	(0.006)
Medium or strong 3G/4G	-0.001	0.002	-0.000	0.001	-0.017**	0.006
for one year	(0.009)	(0.006)	(0.007)	(0.010)	(0.009)	(0.008)
Medium or strong 3G/4G	0.000	0.008	0.007	-0.001	-0.015*	0.002
for two years or more	(0.009)	(0.005)	(0.007)	(0.009)	(0.008)	(0.009)
Medium or strong 3G/4G	0.011	0.016***	0.014*	0.014	0.003	0.009
for three years or more	(0.009)	(0.006)	(0.008)	(0.009)	(0.008)	(0.008)
# of observations	19,167	21,463	24,003	16,018	17,660	22,970
	Age		Locality Type		Education	
	Under 30	30 or older	Rural	Urban	Primary or more	Less than primary
Access to:						
Medium or strong 3G/4G	-0.001	0.008	0.008	-0.007	0.003	0.010
	(0.007)	(0.007)	(0.006)	(0.014)	(0.007)	(0.010)
Medium or strong 3G/4G	0.007	-0.008	0.005	-0.013	-0.001	0.012
for one year	(0.008)	(0.008)	(0.006)	(0.013)	(0.007)	(0.010)
Medium or strong 3G/4G	0.013*	-0.008	0.001	0.006	0.004	-0.001
for two years or more	(0.008)	(0.007)	(0.006)	(0.012)	(0.007)	(0.009)
Medium or strong 3G/4G	0.033***	-0.007	0.010	0.021*	0.015**	-0.004
for three years or more	(0.008)	(0.007)	(0.006)	(0.011)	(0.007)	(0.008)
# of observations	19,044	18,582	28,668	11,962	28,925	4,971
	Literacy		Children under 3			
	Illiterate	Literate	No	Yes		
Access to:						
Medium or strong 3G/4G	0.004	0.005	-0.000	0.008		
	(0.006)	(0.008)	(0.008)	(0.007)		
Medium or strong 3G/4G	0.003	-0.002	-0.000	0.002		
for one year	(0.006)	(0.008)	(0.008)	(0.008)		
Medium or strong 3G/4G	0.005	-0.001	0.002	0.006		
for two years or more	(0.008)	(0.008)	(0.008)	(0.007)		
Medium or strong 3G/4G	0.004	0.012	0.018**	0.012		
for three years or more	(0.008)	(0.007)	(0.009)	(0.007)		
# of observations	11,719	28,161	17,798	22,832		

Notes: Standard errors reported in parentheses are clustered by LGAs. All these regressions include the additional set of controls (e.g., access to electricity, ownership of dwelling, household size, and a wealth index) although the coefficients for these variables are not reported to save space. *** p<0.01, ** p<0.05, * p<0.1.

Table A 7: Impact of 3G/4G access on non-farm self employment by group

	Gender		Consumption		Region	
	Male	Female	Low	High	South	North
Access to:						
Medium or strong 3G/4G	0.002	0.007	0.004	0.002	0.009	0.000
	(0.012)	(0.013)	(0.012)	(0.012)	(0.011)	(0.015)
Medium or strong 3G/4G	0.007	0.000	0.006	0.005	0.010	-0.004
for one year	(0.010)	(0.012)	(0.011)	(0.012)	(0.010)	(0.013)
Medium or strong 3G/4G	-0.001	0.008	0.010	0.008	0.002	0.004
for two years or more	(0.011)	(0.011)	(0.012)	(0.011)	(0.010)	(0.015)
Medium or strong 3G/4G	-0.009	0.016	0.002	0.021*	-0.001	0.011
for three years or more	(0.011)	(0.011)	(0.012)	(0.012)	(0.009)	(0.017)
# of observations	19,163	21,458	23,999	16,013	17,659	22,962

	Age		Locality Type		Education	
	Under 30	30 or older	Rural	Urban	Primary or more	Less than primary
Access to:						
Medium or strong 3G/4G	0.012	-0.002	0.002	0.009	0.000	0.012
	(0.012)	(0.012)	(0.011)	(0.019)	(0.010)	(0.027)
Medium or strong 3G/4G	0.008	-0.001	0.010	-0.010	0.005	-0.007
for one year	(0.011)	(0.011)	(0.011)	(0.014)	(0.009)	(0.026)
Medium or strong 3G/4G	0.004	0.003	0.013	-0.012	0.002	0.020
for two years or more	(0.011)	(0.011)	(0.011)	(0.013)	(0.009)	(0.025)
Medium or strong 3G/4G	0.006	0.002	0.007	0.007	0.005	0.007
for three years or more	(0.011)	(0.011)	(0.011)	(0.013)	(0.009)	(0.026)
# of observations	19,043	18,574	28,661	11,960	28,918	4,971

	Literacy		Children under 3	
	Illiterate	Literate	No	Yes
Access to:				
Medium or strong 3G/4G	0.026	-0.002	0.022*	-0.008
	(0.020)	(0.010)	(0.012)	(0.013)
Medium or strong 3G/4G	0.002	0.004	0.002	0.004
for one year	(0.019)	(0.009)	(0.011)	(0.012)
Medium or strong 3G/4G	-0.012	0.002	0.006	0.000
for two years or more	(0.020)	(0.009)	(0.011)	(0.012)
Medium or strong 3G/4G	-0.005	0.004	0.016	-0.006
for three years or more	(0.021)	(0.009)	(0.011)	(0.013)
# of observations	11,716	28,154	17,796	22,825

Notes: Standard errors reported in parentheses are clustered by LGAs. All these regressions include the additional set of controls (e.g., access to electricity, ownership of dwelling, household size, and a wealth index) although the coefficients for these variables are not reported to save space. *** p<0.01, ** p<0.05, * p<0.1.

Appendix 2: Quasi-experimental approach

Strategy

In this appendix, we set out our strategy to use a quasi-experimental approach to address possible endogeneity concerns in our ITT framework. The approach will be developed further in the next version of the paper, including the use of more data-driven procedures to define key model parameters. The objective of this appendix is to present the intuition behind the analysis as well as some preliminary findings.

The strategy we propose is based on the fact that mobile coverage is heavily influenced by the distance of a household to the nearest mobile site, due do the characteristics of the signal transmission medium. In particular, we exploit a group of households that may get coverage "by accident", in that they were not specifically targeted by operators to receive coverage but did so due to exogenous factors (such as terrain).

In Figure A1, we show the distribution of distances to the nearest 3G site for households that were covered by 3G across all three waves. The majority of covered households resided less than 5km from the nearest 3G site. The remaining households were all within 16km of the nearest site. By contrast, Figure A2 shows that the vast majority of uncovered households were more than 16km from the nearest site. Figure A3 shows the distribution of uncovered households less than 16km from a 3G site.

Figure A1 Distribution of distance to nearest 3G site for **treated (covered)** households

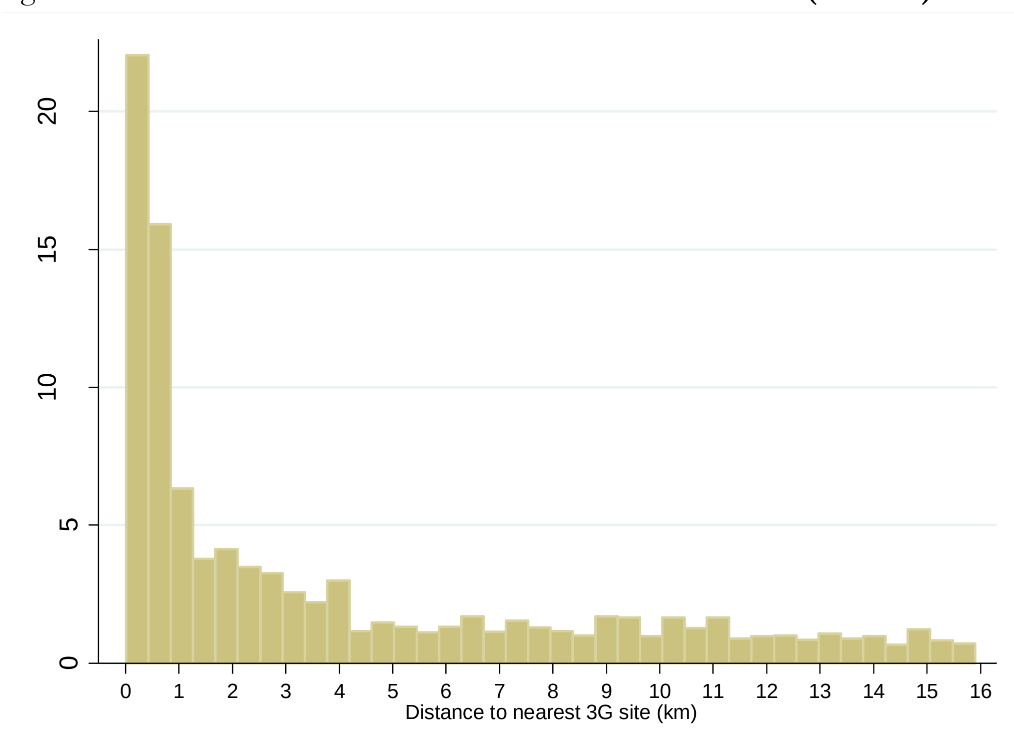


Figure A2 Distribution of distance to nearest 3G site for **untreated (uncovered)** households

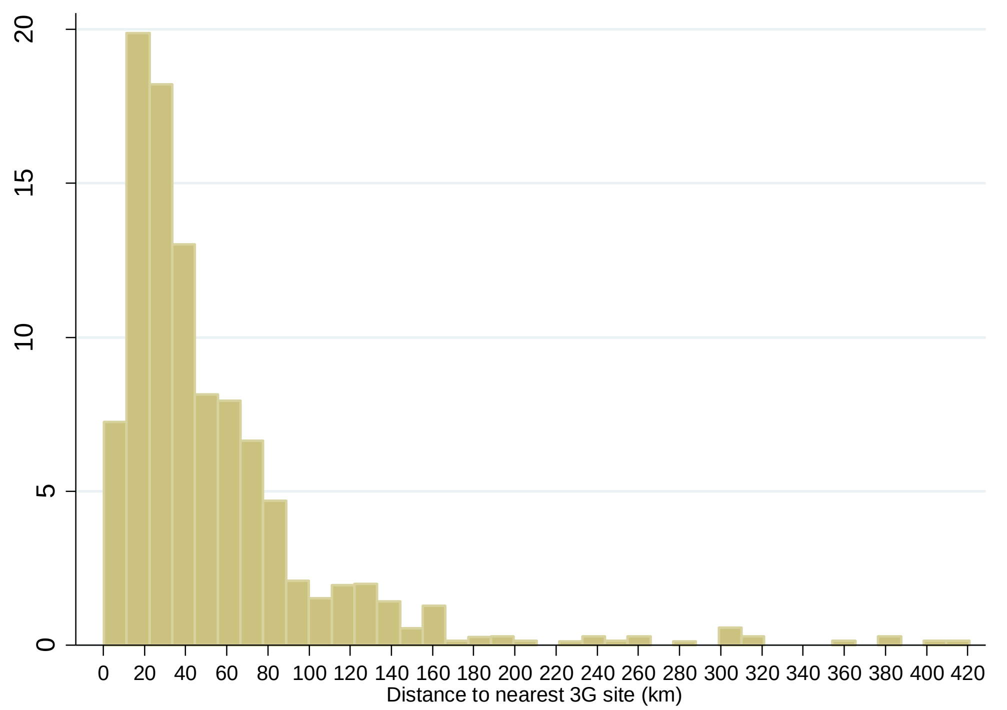
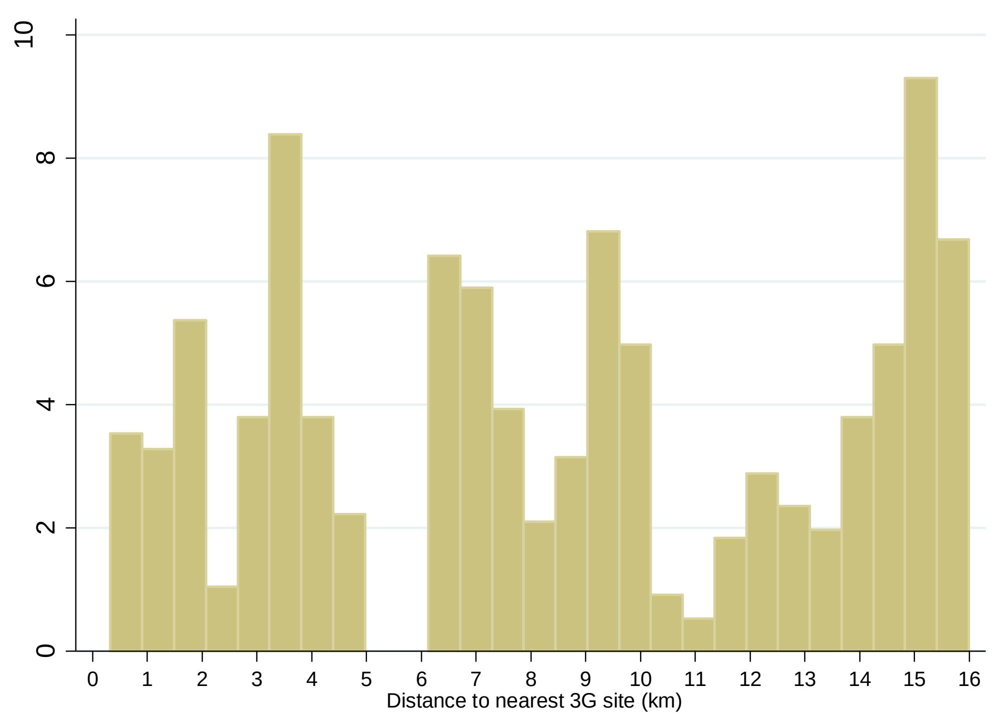


Figure A3 Distribution of distance to nearest 3G site for **untreated (uncovered)** households less than 16km from site



The experimental approach focuses on the households that are located between 5-16km of a 3G site. One can split this group into two categories – those relatively close to a site and those relatively far away. Figure A1 above shows that the majority of treated households were within 5km of site.[39] After this point, the likelihood of being covered for each incremental kilometer of distance is relatively stable, suggesting that these households may not have been the primary targets for operators to cover. Meanwhile, Figure A3 suggests that when looking at the untreated group, there is a degree of randomness in the likelihood of being treated when 5-16km from the nearest site (as the likelihood is not obviously declining as distance increases). We therefore use 5km as a threshold to determine the point at which households are unintentionally covered.

If the main reason why some households more than 5km from a site received coverage and some did not was driven by exogenous factors, then we can use this to isolate the impact of 3G coverage. In order to assess this, we used the Terrain Ruggedness Index (TRI) sourced from EarthEnv.[40] The TRI represents the mean of absolute differences in elevation between a focal cell and its eight surrounding cells – a higher value therefore represents more rugged terrain (for example mountain areas with steep ridges). The dataset we use is aggregated to pixels of 10km, which is merged with our survey dataset. Initial analysis we carried out shows that the average TRI is greater for untreated households than treated households that are between 5-16km from the nearest 3G site.[41] This suggests that exogenous factors such as terrain are indeed a relevant factor in determining whether households have coverage when more than 5km from the nearest 3G site.

Results

As in our main specification, we estimate the following equation:

$$(1)\quad Y_{ijt} = \alpha_i + \beta_1 DT_{ijt} + \beta_2 X_{ijt} + \gamma_t + \varepsilon_{ijt}$$

We apply the same fixed effect regression framework but we restrict the sample to households that were within 5-16km from the nearest site in Wave 3 of the survey. We impose the latter requirement so that the sample only captures households that operators did not intend to cover during the whole period of our analysis, but did so partly due to exogenous factors.

Tables A8-A10 present the results of our fixed effect regressions for household welfare, using indicators for consumption and poverty, when applying the above distance to site thresholds. They show that our main findings, that mobile broadband coverage increases overall consumption and reduces extreme poverty over time, still hold. We also carried out the analysis using first differences and the results remained robust. This initial analysis therefore provides further confidence that the link between mobile broadband coverage and household welfare is indeed causal.

[39] For covered households, the median distance to a site is 1.9km and the 75th percentile is 6.8km.
[40] See http://www.earthenv.org/topography and Amatulli et al (2018)
[41] The average TRI is 2.1 for treated households and 2.3 for untreated households.

Table A8: Consumption results – Households 5km-16km from nearest site

	(1)	(2)	(3)	(4)
Access for one year or more to 3, or 4G	0.019 (0.037)			
Access for two years or more to 3, or 4G		0.075** (0.037)		
Access for three years or more to 3, or 4G			0.087** (0.0402)	
Months covered 3 or 4G				0.003** (0.001)
Observations	3,503	3,503	3,503	3,503
R-squared	0.083	0.085	0.086	0.086
Control variables	Yes	Yes	Yes	Yes

Notes: Standard errors reported in parentheses are clustered by LGAs. All these regressions include the additional set of controls (e.g., access to electricity, ownership of dwelling, household size, and a wealth index) although the coefficients for these variables are not reported to save space. *** p<0.01, ** p<0.05, * p<0.1.

Table A9: Poverty results (based on $1.90 threshold) – Households 5km-16km from nearest site

	(1)	(2)	(3)	(4)
Access for one year or more to 3, or 4G	-0.040 (0.034)			
Access for two years or more to 3, or 4G		-0.079** (0.033)		
Access for three years or more to 3, or 4G			-0.069** (0.035)	
Months covered 3 or 4G				-0.003*** (0.001)
Observations	3,503	3,503	3,503	3,503
R-squared	0.044	0.047	0.046	0.049
Control variables	Yes	Yes	Yes	Yes

Notes: Standard errors reported in parentheses are clustered by LGAs. All these regressions include the additional set of controls (e.g., access to electricity, ownership of dwelling, household size, and a wealth index) although the coefficients for these variables are not reported to save space. *** p<0.01, ** p<0.05, * p<0.1.

Table A10: Poverty results (based on $3.20 threshold) – Households 5km-16km from nearest site

	(1)	(2)	(3)	(4)
Access for one year or more to 3, or 4G	-0.025 (0.027)			
Access for two years or more to 3, or 4G		-0.029 (0.028)		
Access for three years or more to 3, or 4G			-0.045 (0.030)	
Months covered 3 or 4G				-0.002* (0.001)
Observations	3,503	3,503	3,503	3,503
R-squared	0.039	0.040	0.040	0.041
Control variables	Yes	Yes	Yes	Yes

Notes: Standard errors reported in parentheses are clustered by LGAs. All these regressions include the additional set of controls (e.g., access to electricity, ownership of dwelling, household size, and a wealth index) although the coefficients for these variables are not reported to save space. *** p<0.01, ** p<0.05, * p<0.1.

Appendix 3: Endogeneity due to movements to coverage areas

In this appendix we address one last concern with our identification strategy: That households move in response to the expansion of 3G/4G coverage. In our estimations we implicitly assumed that that coverage comes to households, but not vice-versa. That is, households are assumed to stay put, or at least only move due to factors that are assumed orthogonal to treatment roll-out. Movements are quite rare in our sample. Only 42 households in our final sample move between LGAs, and only 28 between states (which would be included in the former 42). We created an outcome variable based on households' geographical coordinates in different waves. This captures moves between LGAs, states, but also moves within the same LGA. Between waves one and two, 4.65% of households moved, between waves two and three, 7.75% did.

The assumption of no endogeneity in movement can be directly tested by regressing this binary variable on the change in coverage. Results for this exercise are shown in table A 11. The model regresses the binary indicator, which can itself be thought of as a first difference, on first differenced right-hand side variables. As before, results are shown for the specification with a full set of control variables. Results are statistically insignificant, except for coverage for more than three years, which show statistically significant results at the ten-percent level, but with a negative point estimate. Given the set-up of our estimation, this would indicate fewer households moving into areas with high coverage after more than three years of receiving 3G/4G coverage. However, the sign of this effect is the opposite than the one that warrants our concerns- which is that higher coverage attracts better-off households.

Table A11: Results for household move as the dependent variable

	(1)	(2)	(3)	(4)
Medium or strong 3/4G	-0.002			
	(0.009)			
Medium or strong 3/4G more than one year		0.006		
		(0.009)		
Medium or strong 3/4G for more than two years			-0.005	
			(0.008)	
Medium or strong 3/4G for more than three years				-0.014*
				(0.008)
Observations	8,471	8,471	8,471	8,471
R-squared	0.004	0.004	0.004	0.004
Control variables	Yes	Yes	Yes	Yes

Notes: Standard errors reported in parentheses are clustered by LGAs. All these regressions include the additional set of controls (e.g., access to electricity, ownership of dwelling, household size, and a wealth index) although the coefficients for these variables are not reported to save space. *** p<0.01, ** p<0.05, * p<0.1.