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Narrowing the 'digital divide': the role of fixed and mobile infrastructure *

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Abstract

We study substitution between fixed and mobile broadband services in South Africa using survey data on 134,000 individuals collected between 2009 and 2014. In our discrete-choice model, individuals choose fixed or mobile voice and data services in a framework that allows these services to be considered substitutes or complements. We find that there is substantial heterogeneity in the perception of these services as substitutes/complements. We use our model to simulate the uptake of fixed and mobile broadband across various demographic groups under different policy interventions, including: (i) a reduction in mobile data prices; (ii) an expansion in fixed-line coverage; (iii) a widespread distribution of computers; and (iv) broader internet access in schools and workplaces. Our results suggest that, when applied in isolation, these interventions do not significantly increase internet access among poorer households. In particular, the uptake of fixed broadband would remain limited, even if accessible to all households. This is because many households prefer mobile internet access, perceiving it as a substitute for fixed broadband.

Keywords: fixed-to-mobile substitution; mobile broadband; fixed broadband; digital divide

JEL Classification: L13, L43, L96

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1 Introduction

The lack of universal and affordable access to broadband infrastructure is a major constraint to economic growth in developing countries. Indeed, Hjort and Poulsen (2019) show that there is a positive impact of fixed broadband on employment and labour productivity in African countries.[1] As a result of this, many developing countries have developed national broadband plans, which envision a range of interventions to expand access to the internet, such as investing in fixed and mobile broadband infrastructure, and expanding access to devices that can use the internet. However, there is a question as to whether such interventions will result in additional uptake of broadband services.

We contribute to this debate by estimating a model of demand for fixed and mobile services. Our aim is to understand whether it is more beneficial to prioritize the rollout of fixed or mobile infrastructure, or to focus on other policy interventions, such as reducing mobile tariffs, in order to increase internet access among different groups in society. This question is particularly important when considering national broadband plans, as fixed-line infrastructure is either non-existent or limited in developing countries, while mobile connections far outnumber fixed-line subscriptions (see Figure 1).

In instances where fixed coverage exists in developing countries, it is usually limited to urban areas and affluent households. For instance, in South Africa, the legacy of apartheid means that fixed-line broadband usage is predominantly concentrated in areas historically reserved for the white population. This disparity manifests itself in significant differences in the use of fixed-line Internet between racial, regional, and income lines, and is influenced by economic activity within the household, as shown in Figure 2.

As a result, most of the population relies on mobile networks to access the Internet. The COVID-19 pandemic has further exacerbated the 'digital divide' between wealthy and impoverished households, as high-income households were able to transition to remote work and education using both fixed and mobile broadband. In general, mobile networks have the potential to replace fixed-line broadband infrastructure. However, depending on the consumer segment, mobile and fixed broadband access may also complement each other rather than serve as substitutes.

Empirical studies of demand usually do not allow for complementarity between products. The exceptions that model demand for complements include Iaria and Wang (2020), Hendel (1999), Dubé (2004), and Gentzkow (2007). In telecommunications markets, the substitution or complementarity between fixed and mobile services is typically assessed based on cross-price effects. Several articles estimate the cross price effects between fixed and mobile voice services using aggregate country-level data including Ward and Zheng (2012), Grzybowski (2014) and Briglauer et al. (2011), or consumer-

[1] Earlier papers by Jensen (2007), Muto and Yamano (2009) and Aker (2010) provide evidence on the impact of mobile phones on economic development.

level data such as Rodini et al. (2003), Macher et al. (2022), and Ward and Woroch (2010). These papers typically do not allow for heterogeneity in substitution nor do they permit the possibility that products may be complements. An exception is a paper by Grzybowski and Verboven (2016) who use the framework of Gentzkow (2007) and individual-level survey data in EU countries to study substitution and complementarity between fixed and mobile voice services. But they do not model demand for data services which is nowadays more important than voice. In a related paper, Liu et al. (2010) study complementarity between voice, television and data services, but substitutability versus complementarity is not relevant in their study. Moreover, they are concerned only with fixed lines (DSL, local phone, and cable service) and do not include mobile services in their framework.

In this paper, we use the framework of Gentzkow (2007) to model a complete decision problem of consumers using telecommunications services, where they choose between fixed and mobile technologies and between voice and data. The papers by Grzybowski and Verboven (2016) and Liu et al. (2010) are less comprehensive by comparison, as the former focuses on voice services and the latter on fixed services. Moreover, our flexible framework accommodates consumer heterogeneity regarding the substitution or complementarity between technologies. We apply our model in counterfactual simulations to identify factors that could enhance the adoption of fixed and mobile broadband in developing countries, a critical issue from an economic development perspective.

The key empirical challenge in estimating the demand for substitutes / complements is to disentangle the correlation of preferences from true substitution/complementarity.[2] We estimate a discrete choice model using survey data on more than 134,000 people in South Africa for the years between 2009 and 2014 and identify whether individual consumers view fixed and mobile services as substitutes or complements. In our model, individuals can choose one or both fixed and mobile voice and data services. For each individual in the sample, we assess whether fixed and mobile data/voice services are substitutes or complements as a function of observed individual characteristics. We separate substitution/complementarity from correlation in preferences using factors that shift the utility of fixed-line services without shifting the utility derived from mobile. We also rely on changes in prices for various services over time and on differences in choice sets between individuals and over time. In addition, we control for correlation in preferences using a broad set of consumer characteristics. Finally, we follow Petrin and Train (2010) and account for endogeneity between choices of services and prices by using a control function approach, where we use exogenous cost factors such as mobile termination rates, the number of sites, and electricity prices as instruments.

We use our model to simulate the uptake of fixed and mobile broadband to understand what inter-

[2] For a general discussion on the challenges with identifying complementary goods see Samuelson (1974) and Berry et al. (2014).

ventions might best be implemented in national broadband plans in a developing country setting. South Africa is an interesting place to study this. Although mobile data is the main means of connecting, there are also limited-coverage fixed-line networks. Fixed lines were rolled out in South Africa almost exclusively to Whites-only areas during apartheid, which came to an end in 1994. Since then, the growth of fixed-line networks has been facilitated by a more open licensing regime and the expansion of subsea optical fibre cables, which were connected to the African continent over the past decade.[3] In terms of broadband infrastructure, South Africa is therefore positioned between developing countries in Africa, which have very few fixed lines, and developed countries with close to universal fixed-line coverage.

We find that on average both fixed and mobile voice and fixed and mobile data services are substitutes, but there are factors that reduce the degree of substitution. In particular, we find that fixed and mobile data are weaker substitutes for consumers who are self-employed and have a computer. Thus, our analysis confirms that in developing economies people without access to a computer substitute mobile data for fixed broadband access to a greater degree. But once consumers acquire a computer, they will derive more utility from combining mobile and fixed broadband access.

We use our model to evaluate the efficacy of broadband plan interventions designed to enhance internet access and reduce the 'digital divide' between poorer and wealthier households. Governments have several policy options to pursue this goal, including implementing regulations or incentives for expanding fixed and mobile networks in rural areas, subsidizing or distributing electronic devices to impoverished communities, and reducing the cost of internet access for both mobile and fixed networks.

Our counterfactual simulations include a reduction in mobile data prices, an expansion of fixed-line coverage, a widespread distribution of computers, and broader Internet access in schools and workplaces. Despite the considerable expenses involved, our results indicate that these policies lead to relatively small improvements in broadening internet access and mitigating the 'digital divide'. Specifically, we anticipate limited uptake of fixed broadband even if it becomes accessible to all households, as many households prefer mobile Internet access, viewing it as an alternative to fixed broadband. Typically, mobile internet is used on smartphones, whereas fixed broadband often requires a computer, which may be unaffordable for low-income households. However, our simulations suggest that increasing computer access alone will not significantly affect the adoption of fixed broadband among low-income households. Furthermore, a potential 30% reduction in mobile data prices through regulatory intervention is projected to result in a

[3] There were more than 400 licensees granted around 2009, when a court ordered that limited-service licences which were issued under the previous telecommunications law are converted to full-service licences under the new Electronic Communications Act, no. 36 of 2005. Regarding subsea cables, the Seacom cable, which connects the north-east coast of South Africa with countries along the coast of East Africa, India and Europe, became operational in 2009. The East African Submarine Cable System (EASSy) lands in the same area in South Africa and has been operational since 2010. The West Africa Cable System (WACS) landed on the south-west coast of South Africa and began operating in 2012. The cable connects South Africa to countries along the coast of West Africa and in Europe.

3.5 percentage point increase in mobile data penetration, with a negligible decrease in fixed broadband penetration. However, we note that a reduction in mobile prices might exacerbate the 'digital divide'.

One potential explanation for the limited effects of these policies is the presence of demand-side factors that diminish their effectiveness. In particular, a significant portion of the population in South Africa lacks digital literacy and, without proper training, may not fully benefit from online resources and services. This lack of digital literacy is closely related to a highly unequal education system, very high unemployment among low-skilled individuals, and poverty.

The remainder of this article is organized as follows. Section 2 discusses the telecommunications sector in South Africa. Section 3 introduces the econometric framework. Section 4 considers the data used in the estimation. Section 5 presents the estimation results, and Section 6 concludes.

2 Industry

During the period of our study, there were the following developments in mobile and fixed-line networks in South Africa in terms of number of players and coverage.

Mobile networks: Between 2009 and 2014, South Africa's mobile telecommunications sector was dominated by two large operators: MTN and Vodacom. Both commenced their Global System for Mobile (GSM) network rollouts in the mid-1990s. Throughout our period, these leading operators provided most of the population with 2G or 2.5G (EDGE) networks.[4] Two other players, Cell C (which entered the market in late 2001) and Telkom Mobile (a division of the fixed-line incumbent that launched in late 2010), offered partial coverage in years 2009-2014. In areas without their own infrastructure, they relied on roaming agreements with the primary networks. In general, service quality during roaming could be lower due to connectivity issues during handovers to their roaming partners.

Coverage data indicate that by 2009, MTN and Vodacom were providing 3G services to approximately 50% of the population. This expanded to about 90% by 2014. Furthermore, the introduction of 4G technology began in 2013, as illustrated in Figure 3. Although a map of cell phone towers reveals some coverage gaps, these are predominantly in less densely populated areas (as seen in Figure 4a). Overall, the four operators offered voice and data services to almost all consumers in South Africa during the period 2009-2014.

Fixed network: Telkom dominated the fixed-line market in the years 2009-2014 for voice and broadband internet services based on copper lines. Some niche fixed-line networks existed, but they mainly catered to businesses or specific gated communities. Fixed-line copper infrastructure was concentrated in urban zones, which during apartheid were mostly reserved for Whites. These lines were also rolled

[4]Although EDGE meets the 3G standard, it is often referred to as 2.5G.

out in selected regions, which historically were designated for Black, Coloured, and Indian populations, fulfilling Telkom's universal service obligations from the 1990s. In 2001, Telkom began to disconnect poorer households for nonpayment. At that time, prepaid mobile voice services were growing as an alternative to traditional fixed-line voice services, at least for low-income consumers (Hodge, 2005).

For the provision of broadband, a copper line needs to be upgraded to Digital Subscriber Line (DSL). This technology is used to transmit data over traditional copper telephone wires, which connect customer premises to the Local Exchanges (LEs) of the fixed-line operator.[5] By the end of 2009, Telkom had extended the accessibility of DSL to 93% of its LEs. A mapping of Telkom's DSL-enabled exchanges suggests that they were prevalent in urban centres, with some coverage in rural areas (see Figure 4b).

In this analysis, we assume that wherever fixed coverage exists, there is also availability of DSL broadband since, as mentioned above, 93% of Telkom's LEs are DSL-enabled. However, the adoption of DSL broadband by households is significantly below both the fixed-line uptake rate and coverage. In particular, in the period between 2009 and 2014, the average fixed-line penetration among households was 21%, and the penetration of DSL was merely 5.8% (see Table 1).

As an alternative to DSL, fixed broadband can be provided to consumers via Fibre to the Home (FttH). This technology converts electrical signals that carry data into light and transmits them over optical fibers. It can provide speeds that far exceed those achievable with DSL. However, FttH broadband infrastructure was almost nonexistent in 2014. Telkom reported a mere 1,524 FttH connections that year.[6] Therefore, all individuals in our sample must rely on DSL technology to access fixed broadband services.

The South African regulator did not report official statistics on fixed-line coverage and uptake for the period in question. Thus, our estimates are based on Telkom's annual reports and household data from Statistics South Africa (Stats SA). Statistics reported by Telkom indicate that on average about 21% of households used fixed lines during 2009-2014. During this period, 3.03 million fixed lines were used out of a total of 14.42 million households in South Africa, as shown in Table 1. Furthermore, Telkom estimated that the penetration of fixed lines in covered areas was only about 50%, implying that about 42% of households had access to fixed lines (6.06m households out of 14.4m).

The speed of DSL broadband declines with the distance between the Local Exchange and the consumer's premises and therefore varies across individuals. The broadband signal degrades when traversing copper lines due to attenuation, which is termed 'copper loss'. According to speed tests, the average speed for DSL connections in South Africa is comparable to the average speed for 3G mobile connec-

[5]In particular, to provide DSL services to consumers, an operator builds a backhaul network to the LEs, and then installs DSL equipment in the LEs to deliver high-speed Internet over copper lines to customer premises.

[6]See: https://www.telkom.co.za/ir/apps_static/ir/pdf/presentations/investor_day/Alphonzo_Samuels_CTO_Investor_Day_2014.pdf

tions, ranging between 4-10Mbps (see Table 2).[7] In our counterfactual simulations, we consider that all households have DSL coverage. However, if due to distance and quality issues, some households cannot use these connections for fixed Internet access, the take-up of fixed Internet access will be overstated.

3 Econometric Model

We model consumer choices of fixed and mobile voice and data services. We account for the fact that many individuals use fixed and mobile connections together and formulate a discrete-choice model for *bundles* of alternatives following Gentzkow (2007). In our setup, fixed broadband connections are offered by a single network operator, and there are three or four mobile operators depending on the year. An individual consumer i can choose stand-alone voice services on the fixed network ($j = fv$) or combined fixed voice and data services ($j = fd$). Thus, with respect to fixed services, there are three choice alternatives $j \in F = \{0, fv, fd\}$, where $j = 0$ refers to the choice of no fixed services at all.

Next, the consumer can subscribe to mobile operator n and choose stand-alone voice services (mv_n) or combined voice and mobile broadband services (md_n). With respect to mobile services, in 2009 and 2010 there are three mobile networks and seven choice alternatives $k \in M = \{0, mv_1, md_1, mv_2, md_2, mv_3, md_3\}$, where $k = 0$ refers to the choice of no mobile services at all. Between 2011 and 2014, there were four mobile networks and nine choice alternatives, including $\{mv_4, md_4\}$. Therefore, in 2009 and 2010, there are $7 \times 3 = 21$ choice alternatives in areas with fixed-line coverage and $7 \times 1 = 7$ in areas without it. Between 2011 and 2014, there are $9 \times 3 = 27$ choice alternatives in areas with fixed-line coverage and $9 \times 1 = 9$ choices in areas outside of such coverage. Table 3 presents the number of consumers who chose different choice alternatives in 2014, while Table 4 illustrates the changes over time in the number of users of fixed and mobile services.

The stand-alone utility of an individual i from a connection to a fixed network is given by:

$$V_{ij} = \alpha p_{ij} + z_f \lambda_f + x_i \beta_f + \xi_j,$$

where p_{ij} represents the monthly subscription charge for either voice services only ($j = fv$) or voice combined with broadband access ($j = dv$). The vector z_f represents features of fixed-line connections, such as connection speed. The vector x_i describes the individual characteristics that influence the utility derived from the fixed service. Finally, ξ_j denotes unobserved characteristics of product j common to all consumers, such as marketing actions or quality, which can simultaneously shift utility and price.[8]

[7] If households situated at greater distances from LEs prefer using the Internet on mobile networks, the results of DSL speed tests may be underrepresented.

[8] Our notation follows other papers, such as Hökelekli et al. (2017), who also apply the Petrin-Train control function approach to account for potential price endogeneity due to unobserved characteristics denoted by ξ.

In Section 4, we outline three different usage profiles for fixed services. Each consumer with fixed-line coverage is assigned to one usage profile (low, medium, or high) and observes two prices (in addition to no service at zero cost): one for the monthly voice-only subscription and another for the voice and data subscription.

The stand-alone utility derived by an individual i from a connection to a mobile operator, denoted by n, is given by:

$$V_{ik} = \alpha p_{ik} + z_k \lambda_m + x_i \beta_m + \xi_k,$$

where p_{ik} represents the prices paid by individual i for either mobile voice services only ($k = mv_n$), or voice and data services from the same operator ($k = md_n$). The vector z_k includes features of the mobile tariff plan, such as minutes and data allowance. The vector x_i describes the individual characteristics that influence the utility derived from the mobile service. Again, ξ_k denotes unobserved characteristics of product k. Consumers are divided into different usage profiles for mobile voice and data services and choose between tariff plans targeted at different profiles, as discussed in Section 4. Depending on the number of active mobile operators, each consumer observes six prices in the years 2009-2010 and eight prices in the years 2011-2014 (in addition to no service at zero cost).

An individual's utility for a bundle of fixed and mobile services $r \in F \times M$ from different operators is defined as:

$$\begin{aligned}
u_{ir} &= \varepsilon_{ir} && \text{if } j = 0 \text{ and } k = 0 \\
u_{ir} &= V_{ij} + \varepsilon_{ir} && \text{if } j \neq 0 \text{ and } k = 0 \\
u_{ir} &= V_{ik} + \varepsilon_{ir} && \text{if } j = 0 \text{ and } k \neq 0 \\
u_{ir} &= V_{ij} + V_{ik} + \Gamma_{ir} + \varepsilon_{ir} && \text{if } j \neq 0 \text{ and } k \neq 0
\end{aligned}$$

The term Γ_{ir} is the difference between the individual's total utility from the bundle of services r and the sum of the stand-alone utilities of fixed services, V_{ij}, and mobile services, V_{ik}. For singleton bundles, $r = \{0\} \times M$ and $r = F \times \{0\}$, we set $\Gamma_{ir} = 0$. For the real bundles, the services are complements if $\Gamma_{ir} > 0$, substitutes if $\Gamma_{ir} < 0$, and independent if $\Gamma_{ir} = 0$.[9] The error term, denoted by ε_{ir}, follows an i.i.d. type I extreme value distribution.

The notation in other papers using individual-level data and maximum likelihood estimation is not precise in this respect. Grzybowski and Verboven (2016) and Macher et al. (2022) use the two-stage Petrin-Train control function approach without explicitly including the term representing unobserved characteristics in their equations, while Liu et al. (2010) do not control for price endogeneity at all. Other literature using aggregate data, such as Berry (1994) and the Berry et al. (1995), models the error term as unobserved product characteristics and relies on the General Method of Moments (GMM) to control for price endogeneity.

[9] At the time of our analysis there were no fixed-mobile bundles on the market, and so our estimates are not driven by bundle discounts or other contractual benefits. The only mobile operator that could offer such bundles is Telkom Mobile, but it has a market share of 1% or less in our data.

Our prices for mobile and fixed-line connections, which are represented by monthly bills, may be correlated with the error term. Consequently, estimation procedures that rely on i.i.d. errors cannot be used directly. The endogeneity problem may arise because unobserved factors, such as marketing actions or quality, can simultaneously shift demand (consumer choices) and monthly bills (prices). This is partly mitigated by the inclusion of a rich set of consumer characteristics including demographics (such as income, race, age, gender, education and whether the home is owned or rented); employment status (whether self-employed or not, or whether employed in a services-related sector); and geographic information (such as living in a city, town or rural area) (see Table 5). In the estimation, we address the problem of endogeneity using the control function approach proposed by Petrin and Train (2010), discussed in more detail in Section 5.

We estimate one gamma, denoted Γ_{iv}, for a bundle that combines voice services on the fixed-line network with voice services on any mobile network.[10] The second gamma, denoted Γ_{id}, is estimated for a bundle that combines fixed and mobile broadband services, which by default come with voice services. Thus, the second gamma is estimated for a subset of voice service users, as shown in Table 3. Note that we do not consider voice and data services to be substitutes over the period we study. First, voice services cannot be used to search the Internet. Second, the main internet-protocol based messaging app in South Africa, WhatsApp, did not offer voice calls during the period of our analysis.[11]

The substitution (complementarity) coefficients, Γ_{ir}, may depend on consumer characteristics x_i. We define $\Gamma_{ir} = \Gamma_r + x_i\gamma_r$, where Γ_r is the stand-alone value common to all individuals, and $x_i\gamma_r$ accounts for individual-level variation in complementarity or substitution. The heterogeneity of Γ_{ir} depends on the same individual characteristics that determine the utilities of fixed and mobile services. The utility from each of the nine bundles $r \in F \times M$ is specified in the Appendix.

A key challenge in identifying Γ_{ir} is distinguishing the correlation of preferences from true complementarity or substitutability. For instance, observing consumers purchasing two services may simply reflect a correlation in preferences rather than an actual complementarity.[12] To address this issue, Gentzkow (2007) suggested employing variables that influence the demand for one service without affecting the other. First, we use the prices of fixed and mobile services as instruments to shift the utility of one service independently of the other. Furthermore, we introduce separate demand-shifters for fixed-voice and fixed-data services. The demand-shifter for fixed-voice services is the presence of a telephone at work,

[10] We do not estimate separate gammas for voice service on the fixed-line network and voice and data services on mobile network, and vice versa. Since we are interested in fixed and mobile substitution between voice services overall, we estimate a single gamma for voice services.

[11] Voice calls over WhatsApp were introduced only in 2015. See: https://www.engadget.com/2015-03-31-whatsapp-voice-calling-android.html

[12] Arora (1996) and Miravete and Pernías (2010) caution that one cannot definitively infer complementarity (or substitutability) from a positive (or negative) correlation in choices due to potential indirect effects. The same identification issue may persist in our paper.

represented by g_i. This factor should influence the utility of having fixed voice services at home, since fixed-to-fixed calls are very cheap or free in South Africa, while it should not affect the utility derived from mobile services. On the other hand, the demand-shifter for fixed-data services is the ownership of a gaming console, denoted by h_i. Gamers typically need connections with very low latency, a requirement best met by fixed broadband connections at the time. Therefore, owning a gaming console should shift the utility for fixed broadband services without impacting the utility derived from mobile data services.

In addition, we incorporate a comprehensive set of characteristics to account for the correlation between preferences for fixed and mobile services among consumers. The variation in choice set due to the unavailability of fixed-line services to some consumers and the entry of the fourth mobile operator, Telkom Mobile, at the end of 2010, also helps in the identification of complementarity/substitution between fixed and mobile services.

In our model, individuals choose the bundle $r \in F \times M$ that maximizes their random utility. Under the assumption that the terms ε_{ir} are i.i.d. type I extreme value distributed, the random utility maximization results in the following logit choice probabilities:

$$s_{ir} = \frac{\exp\left(V_{ir}\right)}{1 + \sum_r \exp\left(V_{ir}\right)} \tag{1}$$

where $V_{ir} \equiv u_{ir} - \varepsilon_{ir}$ is the component of individual i's utility for bundle r specified above.

The choice probabilities form the basis for the likelihood function applied to the data. The summations in the numerator of (1) are modified to adjust for the limited geographic coverage of fixed broadband and different numbers of mobile operators, depending on the year, as discussed in Section 4. Defining $y_{ir} = 1$ if individual i selects voice bundle r, and $y_{ir} = 0$ otherwise, the log-likelihood function can be written as:

$$\mathcal{L}(\theta) = \sum_i^N \sum_r y_{ir} \log s_{ir}\left(\theta\right). \tag{2}$$

where θ is the vector of all parameters to be estimated. The maximum likelihood estimator is the value of the parameter vector θ that maximizes (2).

We have also considered an alternative mixed logit specification that partially relaxes the i.i.d assumption of ε_{ir} in case any unobserved correlation in preferences is captured in our Γ_r parameters. The mixed logit estimation in which the stand-alone values of Γ_r vary at the level of the individual does not converge, even when the interaction terms with gammas are excluded. This may be because our data are not a panel of individuals, but a combination of cross-sectional data for a few years. However, we include a very rich set of individual characteristics as interaction terms with gammas, which should sufficiently account for the correlation of preferences for both fixed and mobile services. If we were not able to account for the potentially positive correlation of preferences, our estimates of gammas would be biased toward complementarity or less substitution.

4 Data

4.1 Survey data and demographics

In our analysis, we used six waves of the All Media Products Survey (AMPS) for the demand estimation.[13] Each year between 2009 and 2014, AMPS surveyed roughly 25,000 consumers, with the exception of 2013, during which only half that number was included.[14] Prior to data processing, we had nearly 138,000 observations.

The dataset includes information on consumer preferences for various products and services, in addition to personal and household attributes. The survey samples a higher proportion of consumers with higher incomes living in urban areas relative to the total population of the country. Nonetheless, it includes large sample sizes across race, income, and other demographic groups (see Table 5). We incorporate AMPS survey population weights when presenting the outcomes of our counterfactual simulations in Section 5.

Our study aims to model consumer decisions regarding fixed and mobile voice and data services, taking into account the geographic distribution of networks to determine the choices available to consumers. As discussed in Section 2, from 2009 to 2014, the majority of South Africa's population had access to mobile broadband. However, we lack precise information about which individuals in the AMPS survey had access to a fixed network because the data do not include geo-location information. Therefore, we attempted to identify the individuals in the survey who live in areas that were discriminated against during apartheid and, as a result, also likely lacked fixed-line coverage.

During apartheid, the population was segregated into racial groups: Black, White, Indian, and Coloured. Many Black individuals were forced to live in rural 'homelands' and were required to carry passbooks, known as the 'dompas', to gain entry into urban areas. These rural homelands were often linked to specific racial and linguistic groups, and the provinces that incorporated these homelands still reflect these affiliations. Patterns of segregation established during apartheid still persist in the post-apartheid era. We leverage this information to delineate fixed-line coverage from 2009 to 2014. Specifically, after the apartheid system was dismantled in 1994, fixed lines were primarily not expanded

[13] This is an annual survey conducted by the South African Advertising Research Foundation (SAARF), now called the Marketing Research Foundation of South Africa (MRFSA), on buyers of a range of products, in order to match media companies (such as newspapers, TV stations and radio stations) and advertisers of the various products surveyed. Data were made available to us by DataFirst at the University of Cape Town and can be provided on request.

[14] For the July-December 2013 period, several questions used in our model were omitted, rendering the observations unusable.

or were disconnected outside of previously designated Whites-only areas. This was often due to theft of copper cables in rural areas and non-payment for post-paid services.

We use demographic information from the survey to determine whether a household has fixed-line coverage. First, due to the reasons previously mentioned, we assume that all White households, even those in rural areas, have access to fixed lines. Second, we consider that Black and Coloured households in rural areas (i.e., living on farms, etc.) do not have fixed-line coverage. Third, we assume that fixed lines are available to Black, Coloured, and Indian households living in urban areas if the following conditions about their dwelling are met: (i) it has a flush toilet, either inside or outside; (ii) it is classified as a house or flat (not a hut or shack); (iii) it has a water connection; (iv) it has indoor plumbing (e.g., a built-in kitchen sink); and (v) it is connected to electricity (see Figure 5). Households without these facilities almost certainly lived in disadvantaged areas during apartheid and do not have fixed-line coverage.

These assumptions suggest that, according to the AMPS surveys of 2009-2014, fixed line coverage did not change significantly over time and averaged 42% (when using the population weights provided).[15] This is consistent with the 42% fixed-line coverage derived from Telkom's annual reports, as discussed earlier in Section 2 (see Table 1).

Based on the AMPS survey (while applying the survey weights), 15% of the population adopted a fixed-line voice or data service on average during the period 2009-2014. There was a significant decline in the adoption of fixed lines during this period: 18% of the AMPS respondents reported having a fixed connection in 2009, compared to 12% in 2014. These figures align with official Telkom and Statistics South Africa statistics.[16] Thus, although fixed-line coverage remained relatively stable throughout our study period, the number of fixed-line subscribers decreased.[17]

In our model, households without fixed-line coverage are limited to mobile service options. They can choose among no mobile service, mobile voice only, or mobile voice and data provided by active network operators. In contrast, users within a fixed coverage area also have the option of selecting no fixed services, fixed voice, or both fixed voice and data services (see Tables 3 and 4).[18]

[15]It is essential to use population weights to adjust for the AMPS survey sample, which has a higher proportion of people living in urban areas and with higher incomes. Without applying population weights, the fixed-line coverage in the data increases from 65% in 2009 to 67% in 2014.

[16]In the General Household Survey 2009, Stats SA reported that 16.9% of households had a working landline, which is very close to AMPS estimate of 18%. Similarly, in the 2014 report, Stats SA reported a fixed-line household penetration of 11%, closely mirroring the AMPS survey estimate of 12% for that year.

[17]This trend is documented in Telkom's annual reports available at: www.telkom.co.za

[18]We excluded 1,951 observations (out of approximately 136,000) where respondents claimed to have a telephone at home but resided in areas without fixed-line coverage based on our assumptions. We also removed 612 observations from respondents who indicated that they had a mobile internet connection but did not report having a mobile network operator. We conducted robustness checks to determine whether alternative methods for developing a proxy for fixed-line coverage would yield different results. In the first check, we removed the assumption that all White households have fixed-line coverage. This resulted in 2,182 households having a telephone at home but not having fixed-line coverage, which is not very different from our baseline assumption. In the second check, we reinstated the coverage assumption in respect of White households and removed the

The AMPS dataset reveals interesting trends in consumer choices of telecommunications services over time. By far the largest is the growth over time in the proportion of consumers choosing mobile voice and data services, which increases from around 8% of respondents in 2009 to more than 50% in 2014 (see panel 3 in Table 4). There was a small increase in the number of consumers choosing fixed voice & data services from 8.1% to 11.5% over the same period. At the same time, there has been a decline over time in the use of purely voice on both fixed and mobile networks.

The adoption of fixed or mobile connections in South Africa varies significantly according to demographic characteristics, as shown in Table 5. In particular, a substantial proportion of consumers with computers also have a fixed-line broadband connection (25%), compared to just 1% of consumers without a computer who have a fixed-line broadband connection. Furthermore, 49% of consumers with computers use mobile data, compared to 16% of consumers without computers. This pattern aligns with observations from other countries (see Figure 6). The absence of a computer has previously been identified as an obstacle to the adoption of fixed broadband services (see, for example, Hauge and Prieger, 2010). In our counterfactual simulations discussed in Section 5.3, we assume universal computer ownership. Similarly, a higher proportion of people who have an internet connection at work or school utilize fixed and/or mobile data compared to those who do not. We also assume a universal internet connection at work or school for another counterfactual scenario.

As expected, the usage of fixed and mobile services increases with income which in South Africa is strongly correlated with race.[19] The uptake of fixed lines varies significantly more by racial groups than does the uptake of mobiles. While 49% of White consumers have a fixed connection, only 8% of Black consumers do. The fixed and mobile choices among the different language groups generally align with the respective racial groups. The preferences for mobile services are roughly consistent across language groups, but a notably larger proportion of English and Afrikaans speakers (who are predominantly White, Coloured, and Indian) have fixed-line services. Moreover, language and race are closely associated with specific geographic regions (provinces) in South Africa.[20]

assumption that Black and Coloured households in rural areas have no coverage, and find that 1,788 households report a fixed line where there is no fixed-line coverage. Again, this result is very close to our baseline assumption.

[19] As a result of discriminatory policies during apartheid, White people have significantly higher incomes compared to other racial groups. Although Indian people also faced discrimination during apartheid, they benefited from greater access to public resources and from living in urban areas. Consequently, they have higher incomes than Black and Coloured people.

[20] South Africa has eleven official languages. The most commonly spoken languages are Zulu, Xhosa, Afrikaans, English, Northern Sotho (Sesotho sa Leboa or Sepedi), Setswana, and Sesotho. Languages spoken by smaller minorities include Xitsonga, siSwati, Tshivenda, and isiNdebele. The predominant language in KwaZulu-Natal province, the most populous province in South Africa, is Zulu. Xhosa speakers are found mainly in the Eastern Cape. Afrikaans and English are spoken primarily in towns and cities, including in the province of Gauteng. Afrikaans is also spoken in the Western Cape and Northern Cape provinces, both in urban and rural areas, especially among Coloured people. A significant number of Sepedi and Tshivenda speakers reside in Limpopo, while Sesotho speakers primarily live in the Free State, a province bordering Lesotho. Setswana speakers are mostly found in the neighboring North-West province, close to Botswana. Siswati speakers and a significant

We also include a variable that denotes whether a consumer is 'technology savvy', which helps us account for correlations in preferences between fixed and mobile services.[21] We observe that 'technology-savvy' individuals are more likely to adopt both fixed and mobile voice and data services. Overall, they tend to be slightly more inclined to adopt mobile services and less likely to adopt fixed-line services. Additionally, we account for an individual's occupation in a service-related sector, which could influence their preferences.[22] People working in service-related occupations are more likely to adopt fixed and mobile services.

We allow the demographic variables discussed above to influence the degree of complementarity or substitution between fixed and mobile voice and between fixed and mobile voice and data. The impact of these variables is discussed in more detail in Section 5.

4.2 Prices and product characteristics

Prices used in our model were obtained from Research ICT Africa (2010-2015) and Tarifica.[23] Additionally, we supplemented the database using an online archive service, the Internet Archive. We use this data to calculate average monthly bills based on a usage basket methodology, mirroring the approach adopted by the International Telecommunications Union (ITU) and the Organisation for Economic Co-operation and Development (OECD) for cross-country price comparisons. Separate monthly bills are computed for prepaid tariff plans and for three postpaid customer segments: low, medium, and high. This segmentation is consistent with the standard approach used by mobile operators in their marketing campaigns. We categorise individuals from the AMPS survey into these segments using information about their prepaid/postpaid tariff plans, reported cellphone expenditure, and intensity of internet usage. As a result, depending on the customer segment, a set of monthly bills is associated with each individual for the available choice options. Employing this methodology to assign monthly bills to survey participants is essential, as the actual prices paid by consumers are seldom observed by researchers.

We discuss the details of this approach for each of the eight choice options consumers face (excluding

proportion of isiNdebele speakers are in the Mpumalanga province, which borders eSwatini (Swaziland). A considerable number of Xitsonga speakers also reside in Mpumalanga and neighboring Limpopo. Since the Zulu, siSwati, and isiNdebele languages are linguistically and geographically related, we group these languages together as 'Zulu+'. Sepedi, Setswana, Sesotho, Xitsonga, and Tshivenda, mainly spoken in the northern parts of South Africa, are grouped together as 'Sesotho+'.

[21] In the AMPS survey, respondents are asked about their attitudes towards technology, after which they are classified as either 'high' or 'low' in this respect. A very small number are categorized as 'none'; we record these as 'low' in our final dataset.

[22] We created a 'services' dummy variable which takes the value 1 if a persons occupation is (i) professional and technical, (ii) administrative and managerial, (iii) clerical and sales, (iv) transport and communication, or (v) service.

[23] Research ICT Africa is a non-governmental organization that collects data and conducts research on telecommunications in Africa. Tarifica is a market intelligence firm that collects information on the prices of telecommunications services worldwide.

the 'none' alternative): (1) mobile voice, (2) mobile voice and data, (3) fixed voice, (4) fixed voice and data, (5) mobile and fixed voice, (6) mobile voice and data and fixed voice, (7) mobile voice and fixed voice and data, and (8) mobile and fixed voice and data. The average monthly bills between mobile operators and for Telkom fixed-line services for these eight alternatives are presented in Table 6.

Mobile voice services: With respect to mobile voice services (choice option (1)), we categorize consumers as prepaid or postpaid users based on their type of contract. In South Africa, most consumers opt for prepaid plans (80% in our database). Many individuals cannot secure a postpaid contract due to unstable or informal employment, and the labour force participation rate in South Africa is notably low.[24] For voice services, all prepaid consumers are grouped into a single segment. Postpaid users are divided into three segments based on their reported monthly cellphone expenditure: low, medium, and high. Low-use consumers are those with monthly bills ranging from R1-150, medium-use consumers spend between R151-500 per month, and high-use consumers spend more than R500 monthly.[25] We chose these spending brackets to align with the general mobile package offerings and to ensure a sizable number of observations within each category. Approximately 25% of postpaid customers belong to the first group, around 53% to the second, and the remaining 22% to the highest spending group.

Next, we calculate monthly bills for voice services for each consumer segment as follows. We assume varying monthly usage of minutes for each segment: 30 minutes for prepaid (1 minute per day); 180 minutes for low-usage postpaid (6 minutes per day); 540 minutes for medium-usage (18 minutes per day); and 1,080 minutes for high-usage consumers (36 minutes per day). In South Africa, prices differ based on whether calls are terminated within the same network (on-net), on other mobile networks (off-net), or on the fixed network. We assume that 10% of minutes are terminated on fixed lines, and the remaining 90% on mobile networks. Calls terminated on mobile networks are allocated based on the market shares of mobile operators. Furthermore, we assume that 50% of calls occur during 'peak' times and the rest during 'off-peak' times, with some tariffs having different rates for these periods.[26] We use this distribution of calls and the number of calls for the prepaid consumer profile to calculate the monthly cost of voice calls for all available prepaid tariffs on the market each year. Subsequently, we

[24]The "“Quarterly Labour Force Survey,” conducted by Stats SA (publication P0211), indicated that the labour force participation rate was 54.8% in Q4 2009 and 56.8% in Q4 2014. Respectively, the unemployment rate was 22% and 26% using the official definition (active job seekers). Meanwhile, using the expanded definition, which includes discouraged job seekers, the rate fluctuated between 30% and 36%.

[25]The south african currency is subject to significant fluctuation. As of April 2022, one US dollar was approximately 15 Rands.

[26] These usage categories align with the OECD mobile voice call baskets (see “Revised OECD Telecommunications Price Baskets”, 2017) which assume that 46% of calls occur during the day, 27% during the evening, and 27% over the weekend. In South Africa, calls made during weekends and evenings are collectively classified as 'off-peak'. Call quantities also align closely with the minutes of use reported by Vodacom in its annual reports from 2009 to 2014 for both prepaid and postpaid customers. On the Vodacom network, prepaid customers used between 52 and 116 minutes per month on average, depending on the year, while postpaid consumers used between 182 and 240 minutes per month.

select the tariff plan with the lowest monthly bill for each operator for each year. Similarly, we calculate the monthly voice bills for the three postpaid consumer profiles, utilising all postpaid tariff plans available on the market annually. In the demand model discussed in Section 3, we assume that when consumers select voice services from different operators, they compare the monthly bills generated in this manner.

We also calculate the cost of terminating voice calls for these four consumer profiles based on their number of calls and the distribution of those calls. This calculation is based on termination rates in South Africa, which vary depending on the operator and between fixed and mobile services.[27] These rates declined from 2009 to 2014 due to regulation. We use these termination costs as instruments in our demand estimation.

Mobile data services: In terms of mobile data, the price is determined by the cost of add-on bundles, which were typically purchased in addition to basic tariff plans. During our period, mobile operators did not differentiate between prepaid and postpaid prices for add-on bundles. These data bundles comprise various data allowances and prices and can be categorized according to customer segments as low, medium, and high. Initially, we group all data bundles advertised by operators into segments based on their purchase value: below R49 for low usage, R50-R149 for medium usage, and higher than R149 for high usage. If an operator offered more than one tariff plan within a segment, we selected the one with the lowest price per gigabyte. We assume that consumers purchase only one add-on bundle per month, which then corresponds to their monthly bill for mobile data. Additionally, we account for the number of gigabytes (GB) included in each add-on bundle in our model.

Next, we classify all consumers into low, medium, and high data use categories based on their declarations regarding Internet use in the survey. Low mobile data users reported being connected to the Internet via mobile phone, but did not use additional services such as instant messaging and email. Medium users reported using mobile data for instant messaging and email, while high users stated that they utilized mobile data for photos and video, in addition to instant messaging and email. The volumes of mobile data allowed for these user categories increased over time, and we account for this in our model (Table 7).

We compute monthly bills for mobile voice and data services (choice option (2)) using the profiles defined above. Consumers might belong to different voice and data profiles in terms of usage intensity, and the bills they observe are assigned accordingly. For example, in 2014, a postpaid customer on the MTN network with a high-usage voice profile (usage of 1,080 minutes) would pay a monthly bill of R1,102 for voice services. If the consumer also had a high-usage data profile, he would pay a monthly data bill

[27] There is a nuanced distinction between the termination rates for long-distance and local calls to fixed-line networks in South Africa. In practice, most interconnection with the fixed line network occurs at the local level to benefit from the lower termination rate. Therefore, we use the local fixed-line termination rate for calls to fixed networks.

of R399 (using 5GB at R79.80 per gigabyte). Thus, when opting for mobile voice and data services from MTN, this consumer would need to pay R1,102 for voice services and R399 for data services.

Fixed-line services: Fixed-line services can be purchased as voice only (our choice option (3)) or as a bundle of voice and broadband (option (4)). In South Africa, no data-only option ("naked DSL") is available. As such, there are tariff plans for voice-only services and for bundles of voice and data, offered by the fixed-line incumbent, Telkom, as discussed in Section 2. Voice-only services are not tailored to different usage profiles; There is a single voice-only tariff plan that includes a monthly allowance of minutes, and it is used by all consumers.

During most of the years of our study period, fixed broadband tariff plans were classified into three user profiles: low, medium, and high. In the cases where multiple fixed-tariff plans were available for a specific profile, we opted for the plan offering the lowest price per gigabyte. Furthermore, we classified fixed broadband users from the survey data into low, medium, and high profiles. Low fixed-data users reported basic internet connectivity. Medium users engaged in online activities such as email, banking, and news access. High-users used the Internet for more data-intensive services, such as streaming television and gaming, in addition to the activities mentioned above. For example, a consumer with high data usage would incur a monthly cost of R904, receiving 40GB of data over a 10-megabit-per-second line and enjoying unlimited voice calls to other fixed lines.[28] Over the years, the speeds of fixed-line broadband services have increased, and our model takes this into account, reflecting the average connection speeds available to various consumer profiles (as detailed in Table 7).

Mobile and fixed-line bundles: To calculate the monthly bills for the bundled options (5)-(8), we aggregate the monthly bills of the individual components based on our previous calculations. Consequently, for mobile and fixed voice (option (5)), we combine monthly bills for mobile voice (option (1)) and fixed voice (choice option (3)). The monthly bill for the combination of mobile voice and data with fixed voice (option (6)) is the sum of the monthly bills for mobile voice and data (option (2)) and fixed voice (option (3)). Similarly, the combination of mobile voice with fixed voice and data (option (7)) is calculated by adding the monthly bills for mobile voice (choice option (1)) and fixed voice and data (option (4)). Finally, the combined monthly bill for both mobile voice and data, as well as fixed voice and data, integrates the bills for mobile voice and data (option (2)) and fixed voice and data (option (4)). Table 6 shows the average bills for these bundled options across various operators and consumer profiles over time.

[28] Telkom began introducing uncapped data plans towards the end of our period. These plans were considerably more expensive than their capped counterparts.

5 Empirical Results

5.1 Control function

First, we estimate a control function for monthly bills to address the potential endogeneity of this variable in our discrete choice model (see Table 8). The endogeneity problem may arise because unobserved factors, such as marketing actions or quality, can simultaneously shift demand (consumer choices) and monthly bills (price). We correct for endogeneity following a two-stage estimation approach proposed by Petrin and Train (2010). The idea behind the control function correction for endogeneity is to derive a proxy variable for the endogenous part of the price, ensuring that the variation in this variable that is used to estimate the model is not correlated with the error term. This control variable is derived from the first stage of a two-stage estimation process.[29]

In the first-stage regression, we use measures of costs as excluded instrumental variables, as well as a set of dummy variables for operators and market segments. In particular, in the case of fixed and mobile voice services, we use termination costs, which are the main cost drivers of mobile voice calls. These costs are set by the regulator, ensuring that they are not correlated with demand shocks and quality. In South Africa, termination rates vary between large and small mobile operators; MTN and Vodacom are required to charge a lower rate than Cell C and Telkom, and there is a separate rate for fixed-line voice services. Over time, these rates have decreased substantially as a result of regulation.[30] Our findings indicate that average termination rates are positively related to average voice prices in the control function regression, as shown in Table 8. This is consistent with the findings of previous studies, such as Genakos and Valletti (2015). We also observe significant differences in the average price of calls and the average cost of termination between different usage profiles and network operators.

Regarding mobile data services, we use the number of sites, which does not respond to short-term demand shocks because it takes up to three years to obtain government approval for a new site.[31]

[29]Goolsbee and Petrin (2004) propose an alternative two-stage approach to account for endogeneity. In the first stage, a discrete choice model is estimated including fixed effects for all the products in the choice set. These fixed effects are then regressed on price and other product characteristics in the second stage. We cannot use this approach here, as consumers choose only between 21 or 27 alternatives depending on the period.

[30]We compute the termination costs for each mobile operator as follows: we assume that 90% of all calls, regardless of their origin, are terminated on mobile networks, and 10% on the fixed network, reflecting the smaller number of fixed-line connections. We also assume that calls to mobile networks are distributed according to market shares, 50% of calls are made during peak hours and 50% are off-peak, with different termination rates for these two time slots. For fixed lines, we consider differences between long-distance (between 0N) and local (within 0N) calls, but most operators pay only the local termination rate due to interconnections in most '0N' regions. Therefore, we use only the local termination rate for fixed calls. Using these assumptions, we calculate the average termination rate per minute paid by each mobile operator each year. Furthermore, we apply the assumptions described in Section 4 regarding voice minutes per type of usage (prepaid, postpaid low, postpaid medium, postpaid high), and we assume that fixed voice users use 30 voice minutes per month, which is comparable to pre-paid mobile. This allows us to determine a monthly termination cost for each monthly bill available in our dataset.

[31] We collected information on the number of sites from operators' annual reports and public sources.

Additionally, the regulator sets coverage requirements that partially dictate the number of sites. In urban regions, operators are compelled to construct new sites to mitigate radio frequency spectrum shortages, and they recognize that this influences their operational expenses.[32] Furthermore, we observe substantial variations in mobile data prices between different usage profiles and network operators, with a general downward trend over time.

Regarding fixed-line data services, we employ the price of electricity as an instrumental variable because operating DSL networks requires electrical power.[33] The electricity prices are set by the National Energy Regulator of South Africa (NERSA) and remain consistent across different industrial sectors. As expected, our findings indicate a positive correlation between monthly bills and electricity prices.[34]

5.2 Discrete choice model

The results of the multinomial logit regression are presented in Table 9. In column (1), the coefficients on the following variables are estimated: (i) monthly bill (our price), (ii) the number of voice minutes available within the mobile tariff plan, (iii) mobile data volume (in GB), (iv) dummy variables for four mobile operators (estimated relative to the option of not having a mobile phone), (v) a dummy variable indicating the presence of a fixed connection from Telkom, (vi) the fixed broadband speed associated with a tariff plan (in Mbps), (vii) shifters for fixed voice (indicating the presence of a telephone at work) and fixed data (indicating the presence of a gaming console), and (viii) residuals from the control function regression.

The price coefficient has the anticipated negative sign. The coefficients on the dummy variable for having a fixed connection and the dummy variables for mobile operators cannot be directly interpreted due to the interaction terms with consumer characteristics shown in columns (2) and (3), which are discussed below. The utility derived from having a fixed connection shows an increase with higher broadband speeds. Similarly, the utility associated with having a mobile service increases with the volume of data provided (measured in GB), while the coefficient for the number of included minutes is positive but insignificant. The coefficient on the residuals of the first-stage regression is positive and

[32]Since the allocation of 3G spectrum to Vodacom and MTN in 2004 and 2005, and subsequently to Cell C in 2011, no new radio frequency spectrum has been distributed in South Africa. Over time, 3G coverage has expanded to rural areas, increasing from around 50% to 90% population coverage (see Figure 3). Operators also report experiencing higher operational costs in rural areas.

[33]The electricity price used in our model represents the average electricity rate charged by Eskom, South Africa's electricity supply utility, rather than the specific cost of electricity incurred by Telkom. Given that Telkom's facilities vary in size and are distributed throughout South Africa, utilizing the national average electricity price offers a plausible estimation of Telkom's actual electricity expenses. (Source: http://www.eskom.co.za/CustomerCare/TariffsAndCharges/Pages/Tariff_History.aspx)

[34]We can estimate the impact of electricity prices and dummy variables for years in one regression because among 11,050 tariff plan observations, 3,400 include fixed data, and the electricity price is set to zero for the remaining observations. Thus, for each year in our data, there are observations for which the electricity price is zero.

significant, indicating that there is a positive correlation between prices and consumer choices. Inclusion of residuals from the control function regression results in a significantly more negative coefficient on the monthly bill.[35] The coefficients on the shifters of fixed voice (having a telephone at work) and fixed data (having a gaming console) are significant and positive, as expected. They increase the utility of having fixed access but not mobile access, which helps us to identify the substitution/complementarity parameters.

The standalone gamma coefficient for fixed and mobile voice is positive ($\Gamma_v > 0$), while for fixed and mobile data services it is negative ($\Gamma_d < 0$). As shown in columns (4) and (5) of Table 9, there is considerable variation in individual-specific gamma coefficients. To analyze the heterogeneity in perceptions of complementarity and substitution, we compute gamma values at the individual level. This involves adding the coefficients applicable to each individual to the stand-alone gamma values. Upon incorporation of consumer heterogeneity in our sample, the average $\overline{\Gamma}_{iv}$ coefficient for fixed and mobile voice services turns out to be negative and exhibits a decreasing trend over time, as shown in Table 10. This implies that, on average, consumers perceive fixed and mobile voice services as substitutes. But given the distribution of Γ_{iv}, certain types of consumers see voice services as complements (see Table 11 for distribution details). The average $\overline{\Gamma}_{id}$ coefficient for fixed and mobile data is also negative but is larger in magnitude and remains stable over time. We observe that fixed and mobile data services are generally perceived as strong substitutes, albeit the intensity of this substitutability varies significantly across different types of consumers. The strong substitution between fixed and mobile broadband may be driven by the fact that only poor-quality DSL technology was available in South Africa between 2009 and 2014. The degree of substitution may be weaker if higher-quality fibre lines were available. At the same time, mobile technology has also improved significantly since 2014 in South Africa, with uncapped 5G connections now becoming more widely available, and so it is not clear how our results would change if they were based on more recent data.

There is heterogeneity between consumers in several characteristics. In particular, having a computer not only enhances the likelihood of choosing a fixed or mobile service, but also amplifies the utility derived from integrating fixed and mobile data services. Furthermore, older consumers are more likely to take up a fixed-line service. This is consistent with the findings of Macher et al. (2022), who suggest that older consumers tend to spend more time at home, and therefore are more likely to use a fixed line, while younger consumers tend to be more mobile. Older consumers have lower Γ_{id} compared to those between the ages of 15 and 25 when using both fixed and mobile data services, and this discrepancy grows with

[35] We also estimated our demand model using various usage specifications and separate price coefficients for each service, resulting in comparable estimates of price coefficients. However, this modeling approach is not consistent with the principles of utility maximization problem solving, which is a fundamental aspect of our demand model.

age. Similarly, combining fixed and mobile voice services results in a lower Γ_{iv} for older consumers.

Individuals with a high school education (twelve years or more) are more likely to select fixed or mobile services. They experience lower utility when merging fixed and mobile voice services, but no significant impact is observed on the gamma for fixed and mobile data. Renters are less likely than home owners to take up fixed-line services. This result is intuitive because renters are more likely to move between houses and, therefore, are less interested in getting a fixed-line service, which often comes with an installation cost and a contract. At the same time, renters get greater utility from combining fixed and mobile data services.

Employed individuals are less prone to choosing a fixed service, possibly due to their limited time at home, whereas self-employed individuals find more value in combining fixed and mobile data services, potentially because of their likelihood to work from home. Thus, for a higher level of employment and self-employment in particular, the expansion of fixed-line services will increase welfare.

Higher-income consumers show a propensity for fixed and mobile services. However, they exhibit lower gamma values for both fixed and mobile voice services and also derive less utility from combining fixed and mobile data services. This could be attributed to their willingness to use mobile data even when at home, diminishing the perceived utility of adding a fixed-line data service.

These income-related trends extend to racial and language groups, with Indian, Coloured, and White consumers being more likely than Black consumers to opt for a fixed-line service. White consumers also show a greater inclination towards mobile services compared to Black consumers. Afrikaans and Xhosa speakers are less likely to choose fixed and mobile services than English speakers. Moreover, Indian, Coloured, and White consumers find less value in combining fixed and mobile services, both for voice and data, compared to Black consumers.

Females show a higher propensity to adopt fixed and mobile services. At the same time, women exhibit lower gamma values to combine fixed and mobile voice, as well as data services. Individuals residing in larger households tend to be less inclined to opt for fixed and mobile services. This trend could be attributed to the association between larger households and lower average incomes in South Africa, where clustering around recipients of old-age social pensions is common (see Duflo, 2000). An increase in the number of mobile phones within a household is positively correlated with the probability of adopting mobile services, aligning with existing evidence that supports network effects in mobile adoption (see Doganoglu and Grzybowski, 2007). Additionally, households with more cellphones also experience greater utility from integrating fixed and mobile services, both for voice and data. This can be explained by the potential for more calls between fixed and mobile numbers, as well as the ability to connect numerous cellphones to fixed broadband via WiFi.

The 'technology savvy' variable positively influences the adoption of mobile phones, but it does not have a significant effect on the adoption of fixed-line connections. The influence of employment in a services-related sector follows a similar pattern. Furthermore, being 'tech savvy' or working in a services-related sector does not significantly affect the substitution between fixed and mobile voice or data services.

5.3 Counterfactual simulations

We use our model to conduct a series of counterfactual simulations to demonstrate the impacts of potential broadband plan interventions aimed at expanding broadband penetration. These interventions include: (i) a 30% reduction in mobile data prices; (ii) an expansion of fixed-line coverage; (iii) a widespread rollout of computers; and (iv) an increase in Internet access in schools and workplaces. The results are presented in Tables 12 through 14. These simulations are instrumental in evaluating the feasibility of national broadband plan interventions, which are prevalent in many developing countries.[36] Take, for example, South Africa's national broadband plan, SA Connect, which aims for universal broadband access, regardless of the technology used, with an average download speed of 100Mbps by 2030.[37] Our counterfactuals are also important in the context of the COVID-19 pandemic, due to which many people may continue working from home permanently (see Barrero et al., 2020). We do not model the costs of these interventions, which would be substantial and, as our simulations suggest, would result only in limited expansions in broadband penetration. The results of our simulations, using population weights provided in the survey, are as follows.

Our initial simulation addresses the inquiry into the cost of mobile data initiated by the South Africa Competition Commission in August 2017. This inquiry, spurred by persistent public concerns about high data prices, concluded in December 2019, finding that data prices in South Africa were excessively high. Moreover, it identified the retail pricing structures as both anti-poor and lacking in transparency. The Commission recommended that significant and immediate price reductions ranging from 30%-50% be negotiated through independent agreements with relevant mobile operators. Using our model in conjunction with this recommendation, we simulate the impact of a 30% reduction in mobile data prices. Our findings suggest that such a price reduction would result in a 3.5 percentage point increase in mobile data penetration, shifting from 58.4% to 61.9%. In contrast, fixed-line data penetration experiences a negligible decrease, dropping from 7.3% to 7.2%. This outcome underscores the notion that for many consumers, fixed and mobile data services are not highly substitutable (see Table 12). However, it is important to note that reductions in mobile prices may exacerbate the 'digital

[36]For instance, according to the Alliance for Affordable Internet's "2020 Affordability Report" almost all developing countries included in their study have implemented a national broadband plan. For more information, visit: https://a4ai.org/

[37]Refer to "South Africa Connect: Creating opportunities, ensuring inclusion, South Africa's broadband policy, 20 November 2013." Available at: https://www.dtps.gov.za/

divide'. For example, after a 30% price reduction, low-income consumers show a 2.7 percentage point increase in mobile broadband adoption, while high-income consumers exhibit a 4.8 percentage point increase. The effects also vary across different racial groups: mobile broadband penetration climbs by 3.2 percentage points for Black consumers, while White consumers see a 4.6 percentage point increase. In summary, a reduction in mobile data prices appears to have a modest effect on boosting broadband penetration in South Africa. However, our model cannot evaluate the impact on data usage intensity among subscribers and the associated welfare effects, which could potentially be more significant.

In the second scenario, we explore the potential effects of expanding fixed-line DSL broadband coverage from its current level of approximately 42% to encompass the entire sample. Although the cost of deploying fixed broadband is generally quite substantial, there have been instances in South Africa where low-income areas have been fully serviced by affordable fibre networks.[38] Our findings indicate that in this scenario, penetration of fixed line voice and data services would experience a modest increase, increasing from 7. 3% to 8. 5%. Consequently, it seems that consumers currently residing outside of fixed-coverage areas are not inclined to adopt fixed-line services, even if such services were to become universally available. Furthermore, we observe a 0.1 percentage point decrease in the likelihood of choosing mobile data when fixed-line data coverage is expanded. Given that affluent areas already benefit from fixed-line coverage and exhibit an average uptake rate of 24.3% over the period from 2009 to 2014, it follows that uptake in less affluent areas, once covered, would fall below this figure, a prediction confirmed by our simulation. Our results point to a noteworthy conclusion: even if fixed lines were accessible to all households, their adoption would likely remain limited. This is attributed to the tendency of low-income households to favor mobile Internet access, which they perceive as an adequate substitute for fixed broadband. In particular, mobile internet is accessed predominantly via smartphone, while fixed broadband requires the use of a computer, a device that many low-income households may find financially out of reach. Other obstacles that hinder the extension of DSL broadband to low-income regions include the high price of DSL broadband and the necessity of committing to a long-term contract for connection, which in turn requires a credit reference check.

Next, we explore the potential of expanding computer access to bridge the 'digital divide'. Survey evidence in South Africa and other countries identifies the high cost or lack of equipment, such as computers, as a key barrier to using the Internet at home, rather than the price of subscribing to a broadband service alone.[39] Equipping households with computers could be a costly endeavor; however, with the

[38] A case in point is Vumatel, a fibre operator that has introduced fibre-to-the-home services in Mitchells Plain, a sizable low-income community in Cape Town, with a monthly charge of R399 (US$26.8). Based on the 2011 census, Mitchells Plain had a population of 310,485, distributed across 67,995 households, with 38% of these households earning a monthly income of R3,200 (US$215) or less.

[39] For example, in the general household survey run by Statistics South Africa, the most-cited reason for 'not having internet access at home' is 'cost of equipment is too high' (26% of survey respondents that have no internet connection at home). Only 6% of those who do not have Internet access at home cite that their reason for this

fast-declining prices of computers, affordability is on the rise. In 2021, around 27% of the country's 18 million households reported owning a computer.[40] Our simulations suggest that while increasing access to computers increases the value of having mobile and fixed broadband, it will not significantly impact the adoption of fixed broadband among low-income households. Specifically, mobile data penetration would increase by 0.8 percentage points, and fixed broadband by only 1.1 percentage points. However, in this scenario, the coverage of the fixed network remains unchanged and fixed broadband is not available to the majority of rural and poor households.

In the subsequent counterfactual scenario, we extend internet access in schools and workplaces to the entire population. A related study by Goolsbee and Guryan (2006) sheds light on how an internet subsidy and improved connectivity in schools can contribute to narrowing this divide in the U.S.[41] As of 2021, only 20% of public schools in South Africa had internet connectivity for teaching and learning purposes, falling short of the government's ambitious target of connecting all schools by 2020, as outlined in the 2013 SA Connect plan.[42] However, providing internet access to schools seems a feasible goal, given that most school-adjacent communities enjoy 4G mobile network coverage. Furthermore, South Africa's mobile operators commonly use fixed lines (often fibre) for backhaul. Providing internet access at schools and workplaces is projected to increase mobile data penetration by 1.5 percentage points and fixed broadband by a modest 0.3 percentage points (see Table 13). Thus, the effect of implementing this intervention in isolation is relatively small.

Finally, we consider the cumulative effects of expanding fixed-line coverage, enhancing computer accessibility, and facilitating Internet access in schools and workplaces. In this cumulative scenario, fixed broadband penetration would experience a 4.5 percentage point increase, reaching 11.8% (see Table 14), accompanied by a 1.8 percentage point increase in mobile data penetration. Although these effects may seem modest, it is crucial to recognise that enhanced fixed Internet access in homes significantly increases individual internet accessibility, more so than mobile services. This is particularly noteworthy given that the average household size in South Africa is 3.3 people, with even greater figures in rural areas, reaching 4.3.[43] These results, however, are not uniform across different demographic segments, varying by income,

is that the cost of a subscription is too high. Research ICT Africa finds more evidence to corroborate this result, finding in the 2017 'After Access survey that device cost is the largest barrier to internet access in South Africa (see the 2018 report published entitled "The State of ICT in South Africa"). For examples of similar results from surveys in the US, see Hauge and Prieger (2010).

[40] Source: Stats SA, "General Household Survey," 2021, statistical release P0318.

[41] The impact of computers at home and in schools on educational outcomes is a subject of ongoing debate and research. For instance, Banerjee et al., 2007 present evidence suggesting positive effects of the use of technology in schools on educational outcomes in developing countries. While our paper does not delve into this specific aspect of the literature, our simulations offer insights into potential ways to bridge the 'digital divide'.

[42] Refer to the Department of Basic Education National Education Infrastructure Management System Standard Report 2021 and "South Africa Connect: Creating opportunities, ensuring inclusion, South Africa's Broadband Policy," dated 20 November 2013.

[43] Source: Stats SA, 2017, "Living Conditions of Households in South Africa," statistical release P0310.

race, and language. For example, the combined expansion of fixed-line coverage, computer access, and internet availability in schools and workplaces would increase fixed-line broadband penetration among Black households by 4.7 percentage points, climbing from 3.1% to 7.8%. In contrast, White consumers would witness a 3.5 percentage point increase in access, from 30.9% to 34.4%. Similarly, these initiatives would increase fixed-line broadband access by 5.2 percentage points for low-income households, compared to a 3.9 percentage point increase for their high-income households. Consequently, increasing access to fixed lines, computers, and Internet at work or school does play a role in expanding internet penetration, particularly among impoverished households, thus contributing to a narrowing of the 'digital divide'. However, it is important to recognize that this impact is somewhat constrained, given the relatively modest expansion in uptake that these measures bring about.

6 Conclusion

We explore the potential effects of various policy interventions, commonly proposed in national broadband plans. These include enhancing fixed and mobile infrastructure, promoting device accessibility, and minimizing connection costs, all aimed at broadening Internet access and diminishing the 'digital divide.' To accomplish this, we employ a discrete-choice model to analyze the substitution between fixed and mobile services for voice and data in a developing nation characterised by significant poverty and inequality, such as South Africa. We find that, on average, fixed and mobile voice and fixed and mobile data services are substitutes. At the same time, our results show a high degree of variability around the mean, where fixed and mobile substitution depends on a range of individual and household characteristics.

We use our model to perform counterfactual simulations for the following policy interventions: (i) an expansion of fixed-line coverage; (ii) a 30% reduction in mobile data prices; (iii) a widespread distribution of computers; and (iv) broader internet access in schools and workplaces. Our findings suggest that these interventions, when applied in isolation, do not significantly improve internet access among poorer households. Specifically, even if fixed lines were made universally available, the uptake of fixed broadband might not see a considerable increase. This trend can be attributed to the prevailing preference for mobile Internet among many households, as they view it as an alternative to fixed broadband. In particular, mobile Internet is mainly accessed via smartphones, while the use of fixed broadband typically requires a computer - a cost-prohibitive device for many households in South Africa. In particular, our results show that in developing economies, individuals without access to a computer tend to substitute mobile data for fixed broadband at a higher rate. However, once consumers obtain a computer, they find more utility in combining both mobile and fixed broadband access.

Second, a 30% reduction in mobile data prices would increase the penetration of mobile broadband by 3.5 percentage points. However, this reduction in prices could widen the 'digital divide,' leading to more significant broadband penetration among wealthier White consumers than among the poorer Black population. Furthermore, while increasing access to computers enhances the value of having mobile and fixed broadband, it will not significantly impact the adoption of fixed broadband among low-income households. Specifically, mobile data penetration would increase by 0.8 percentage points and fixed broadband by only 1.1 percentage points. However, in this scenario, the coverage of the fixed network remains unchanged and fixed broadband is not accessible to the majority of rural and poor households. Furthermore, providing internet access at schools and workplaces is expected to increase mobile data penetration by 1.5 percentage points and fixed broadband by a modest 0.3 percentage points. Moreover, if computers were available to everyone and all workplaces and schools had internet access, the penetration of fixed line broadband would increase by 1.6 percentage points and the penetration of mobile data would increase by 2.1 percentage points.

These findings have significant implications for regulators and policy makers in developing countries. Our analysis demonstrates that typical interventions featured in broadband plans, such as the expansion of fixed-line coverage and reductions in mobile data prices, do not substantially increase internet access. Furthermore, although supplying the necessary tools for broadband usage, such as computers, can stimulate demand, the impact remains limited. We conclude that despite the substantial expenses incurred, the aforementioned policies produce relatively modest outcomes in terms of widening internet access and bridging the 'digital divide', especially when these policies are implemented individually.

One potential explanation for this outcome is the presence of significant demand-side factors that diminish their effectiveness. In particular, a significant portion of the population in South Africa lacks digital literacy, and without proper training, they may not fully benefit from online resources and services. This lack of digital literacy is closely linked to a highly unequal education system, very high unemployment among low-skilled individuals, and poverty.

It is crucial to note that our analysis focuses solely on adoption and does not constitute a comprehensive cost-benefit evaluation of various policy alternatives. The expansion of access to computers, as well as internet availability in schools and workplaces, involves significant costs, all of which should be considered when assessing the options available to policy makers.

Furthermore, the telecommunications sector is highly dynamic, influencing the demand for both fixed and mobile services. Specifically, there has been rapid growth in innovative services that leverage smartphones and mobile data. For example, during our study period 2009 to 2014, WhatsApp, a leading over-the-top communication service, did not support voice calls. The value of a mobile data connection has been enhanced by these additional applications and technological advancements, potentially altering how consumers perceive fixed and mobile data services as either substitutes or complements. Fixed-line connections have also seen improvements in both speed and quality with the advent of Fibre-to-the-Home (FttH) services, and there is an increasing demand for applications that require very high speeds and low latency. For example, the COVID-19 pandemic led to an increase in remote work and learning, with multiple users often sharing a single connection and utilizing data-intensive applications such as video calling. Furthermore, over-the-top providers such as Netflix and Amazon Prime Video offer ultra-high definition streaming services, which even high-capacity fifth-generation mobile networks, recently introduced in South Africa and other countries, may find challenging to handle due to the substantial data volumes. Given these rapid technological advances that impact both fixed and mobile services simultaneously, it remains unclear how these changes would influence our results. Addressing this question presents a compelling avenue for future research.

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A Appendix

A.1 Utility bundles

In our framework, fixed broadband connections are provided by a single network operator, Telkom, while there are three or four mobile operators available, depending on the year in question. Thus, with respect to fixed services, in the entire period there are three choice alternatives $j \in F = \{0, fv, fd\}$, where $j = 0$ refers to the choice of no fixed services at all. Next, in the years 2009 and 2010, consumers could choose among three mobile networks, leading to seven choice alternatives $j \in M = \{0, mv_1, md_1, mv_2, md_2, mv_3, md_3\}$, with $j = 0$ denoting the option of opting out of mobile services entirely. From 2011 to 2014, a fourth mobile network was added, expanding the choice alternatives to include $\{mv_4, md_4\}$. Consequently, for the years 2009 and 2010, there were $7 \times 3 = 21$ choice alternatives available in regions with fixed-line coverage, and $7 \times 1 = 7$ choices in regions without. From 2011 to 2014, options increased to $9 \times 3 = 27$ choice alternatives in areas with fixed-line coverage, and $9 \times 1 = 9$ choices in areas without.

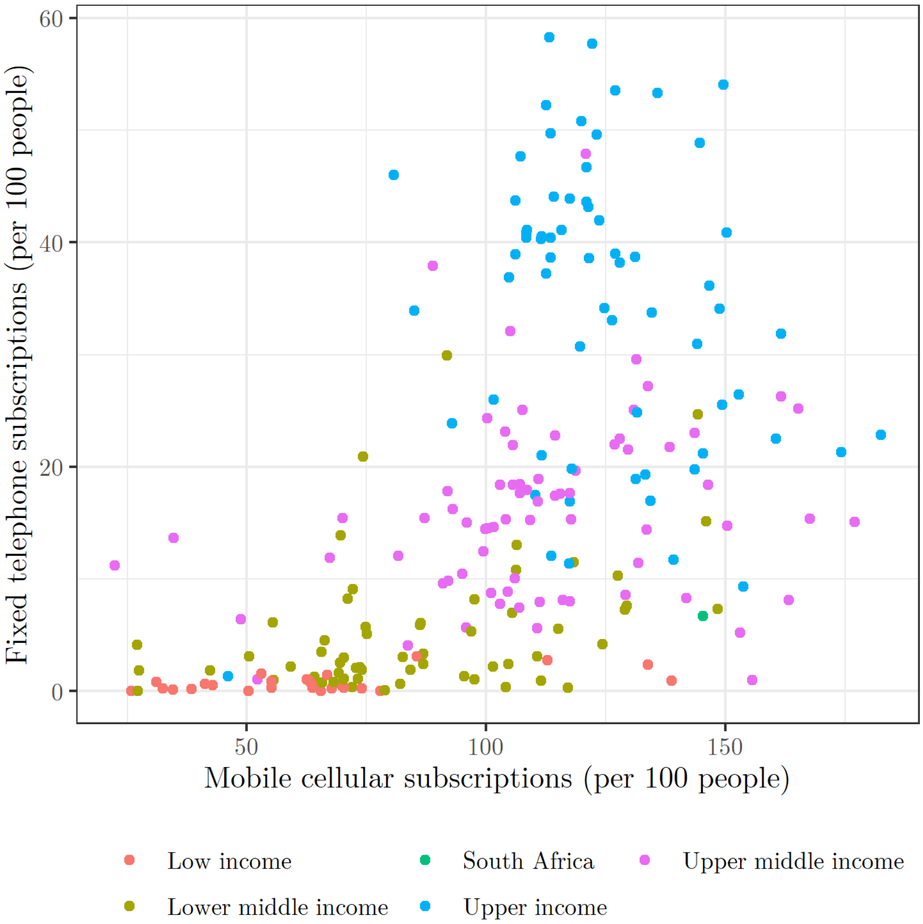
Ignoring the subscript for mobile operators for simplification, the choice options can be summarized as follows: no telecommunications services (0); (1) mobile voice (mv); (2) mobile voice and data (md); (3) fixed voice (fv); (4) fixed voice and data (fd); (5) mobile and fixed voice ($mv + fv$); (6) mobile voice and data with fixed voice ($md + fv$); (7) mobile voice with fixed voice and data ($mv + fd$); and (8) mobile and fixed voice and data ($md + fd$). Based on the information provided in Section 3, the utility specifications for these alternatives can be expressed as follows:

$$
\begin{aligned}
u_{i0} &= \varepsilon_{i0} \\
u_{imv} &= \alpha p_{imv} + z_m \lambda_m + x_i \beta_m + \xi_{mv} + \varepsilon_{imv} \\
u_{imd} &= \alpha p_{imd} + z_m \lambda_m + x_i \beta_m + \xi_{md} + \varepsilon_{imd} \\
u_{ifv} &= \alpha p_{ifv} + z_f \lambda_f + x_i \beta_f + \beta_{fv} g_i + +\xi_{fv} + \varepsilon_{ifv} \\
u_{ifd} &= \alpha p_{ifd} + z_f \lambda_f + x_i \beta_f + \beta_{fv} g_i + \beta_{fd} h_i + \xi_{fd} + \varepsilon_{ifd} \\
u_{imv+fv} &= \alpha p_{imv+fv} + x_i(\beta_m + \beta_f + \gamma_v) + z_m \lambda_m + z_f \lambda_f + \Gamma_v + \beta_{fv} g_i + \xi_{mv+fv} + \varepsilon_{imv+fv} \\
u_{imd+fv} &= \alpha p_{imd+fv} + x_i(\beta_m + \beta_f + \gamma_v) + z_m \lambda_m + z_f \lambda_f + \Gamma_v + \beta_{fv} g_i + \xi_{md+fv} + \varepsilon_{imd+fv} \\
u_{imv+fd} &= \alpha p_{imv+fd} + x_i(\beta_m + \beta_f + \gamma_v) + z_m \lambda_m + z_f \lambda_f + \Gamma_v + \beta_{fv} g_i + \beta_{fd} h_i + \xi_{mv+fd} + \varepsilon_{imv+fd} \\
u_{imd+fd} &= \alpha p_{imd+fd} + x_i(\beta_m + \beta_f + \gamma_v + \gamma_d) + z_m \lambda_m + z_f \lambda_f + \Gamma_v + \Gamma_d + \beta_{fv} g_i + \beta_{fd} h_i + \xi_{md+fd} + \varepsilon_{imd+fd}
\end{aligned}
$$

In these equations, p_{ir} represents the price of the bundle r. The vector z_f represents features of fixed-line subscription, while z_m represents features of mobile subscription. The vector x_i corresponds to individual characteristics. The additional fixed-voice shifter, denoted by g_i, indicates whether an individual has a telephone at work. The additional fixed-data shifter, denoted by h_i, indicates whether an individual has a gaming console. The coefficients Γ_v and Γ_d are the stand-alone substitution (complementarity) coefficients that are common to all individuals. Finally, ξ_r denotes unobserved product characteristics that are also common to all individuals, may shift prices, and are accounted for using the control function approach.

A.2 Figures

Figure 1: Digital divide (i): Fixed-line and mobile cellular telephones per 100 population are higher among countries that have greater GNI per capita, 2014

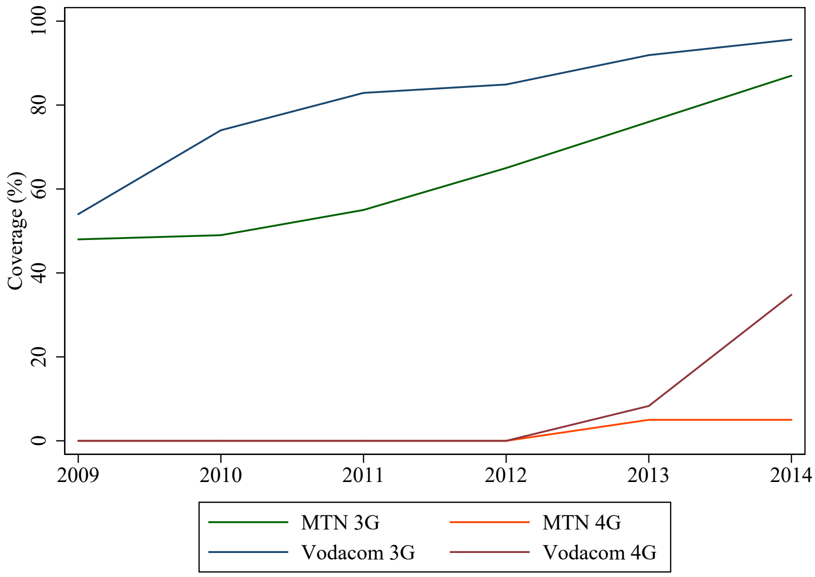


Source: World development indicators from the World Bank. Note that each dot is a country, and income categories are as defined by the World Bank Gross National Income (GNI) per capita, using 2014 data: low-income is less than or equal to $1,045; lower middle income lies between $1,046-4,125; upper middle income between $4,126-12,735; and high income greater than $12,735.

Figure 2: Digital divide (ii): internet connections are highly unequal between households in South Africa, by race, geography, income and whether economically active (2009-2014)

Source: Statistics South Africa, General Household Surveys 2009 and 2014. Notes: Income means monthly income in South African Rands. Economically active means number of members of household that are economically active (i.e. working or would accept a job).

Figure 3: 3G and 4G population coverage in South Africa, 2009-2014 (%)



Source: MTN and Vodacom annual reports. Note that EDGE (referred to as '2.5G', though it technically meets the standard for 3G) coverage was close to complete over this period for the MTN and Vodacom networks.

Figure 4: Maps indicating cell sites and fixed-line local exchanges

(a) Approximate locations of cell masts (2017) **(b) Telkom fixed-line local exchanges (2014)**

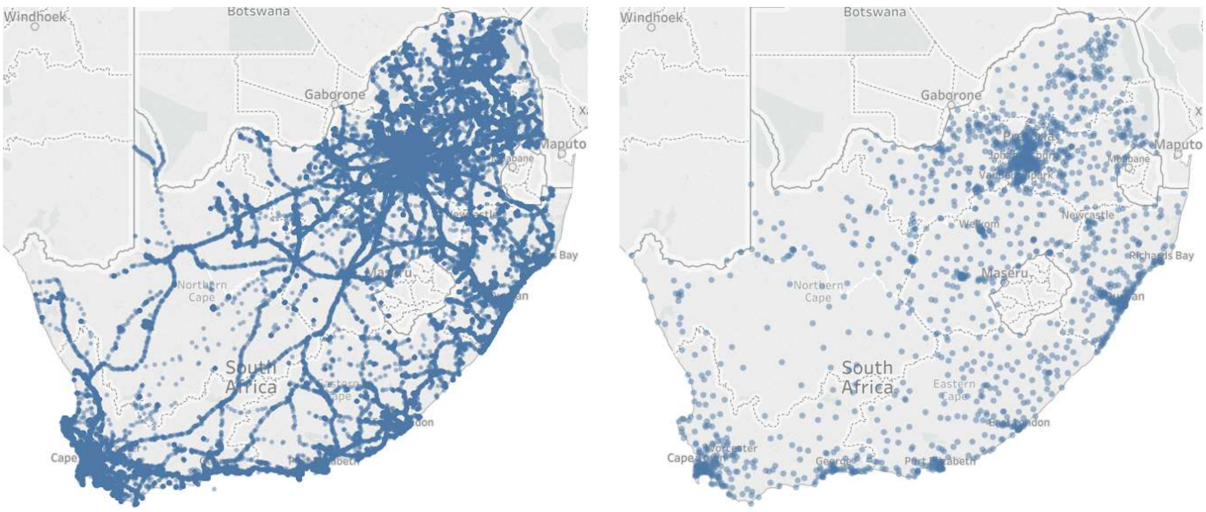
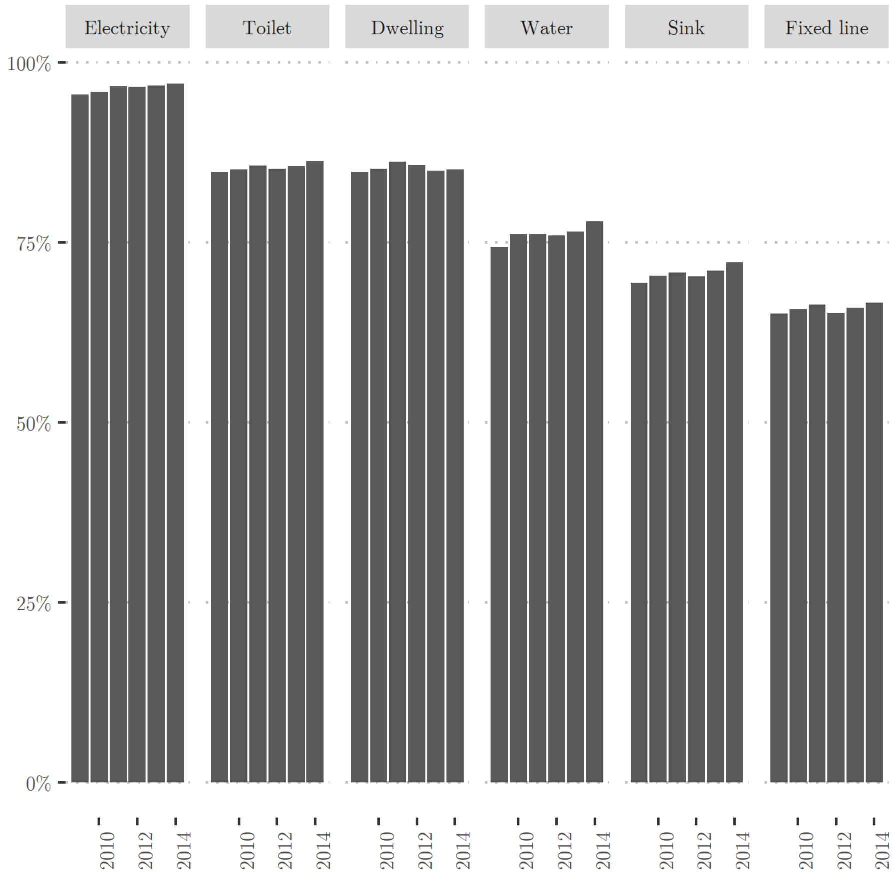


Figure (4b) shows locations of 1,864 local exchanges identified by broadbandstats.co.za in 2014. Figure (4a) shows estimates of high site and mast positions obtained from opensignal.com in September 2017. These estimates are based on signal strength to smartphones that have the OpenSignal application installed. Note that number of sites by operator used in the control function for data prices (reported in Table 8) uses number of masts and high sites reported by the mobile operators in annual reports and other public sources.

Figure 5: Identifying areas with no fixed-line coverage (%)



AMPS survey respondents, 2009-2014 (N=137,321). Note that: (i) electricity means there is an electricity connection, (ii) toilet means has a flush toilet inside or outside, (iii) dwelling means a house or flat (and not a hut or a shack), (iv) water indicates there is water connection, and (v) sink means there is indoor plumbing (a built-in kitchen sink). The last facet ('Fixed-line') indicates the proportion of AMPS respondents coded as having fixed-line coverage.

Figure 6: Having internet access at home is associated with having a computer, and higher-income countries have more of both (2012-2016)

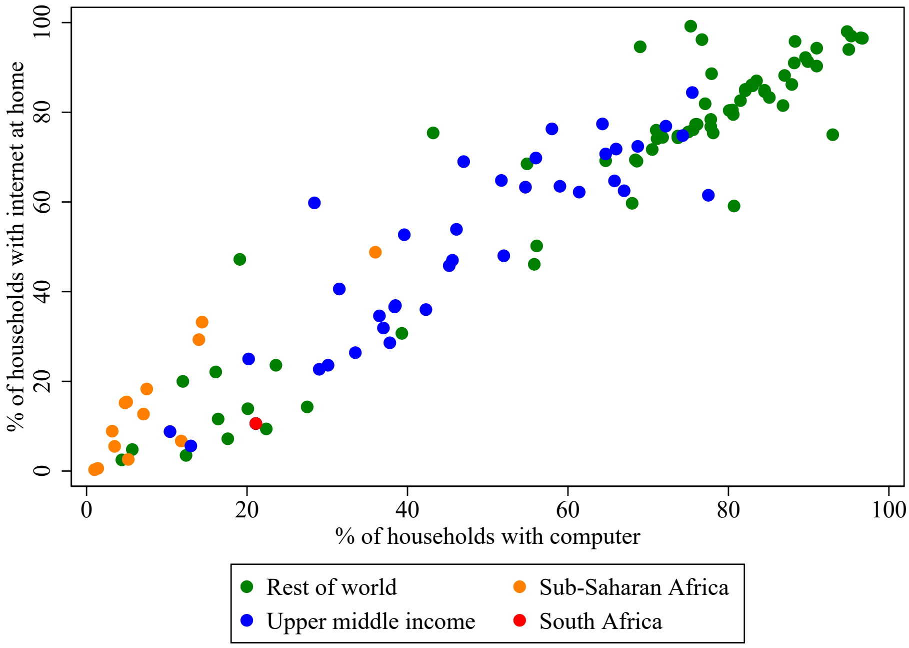
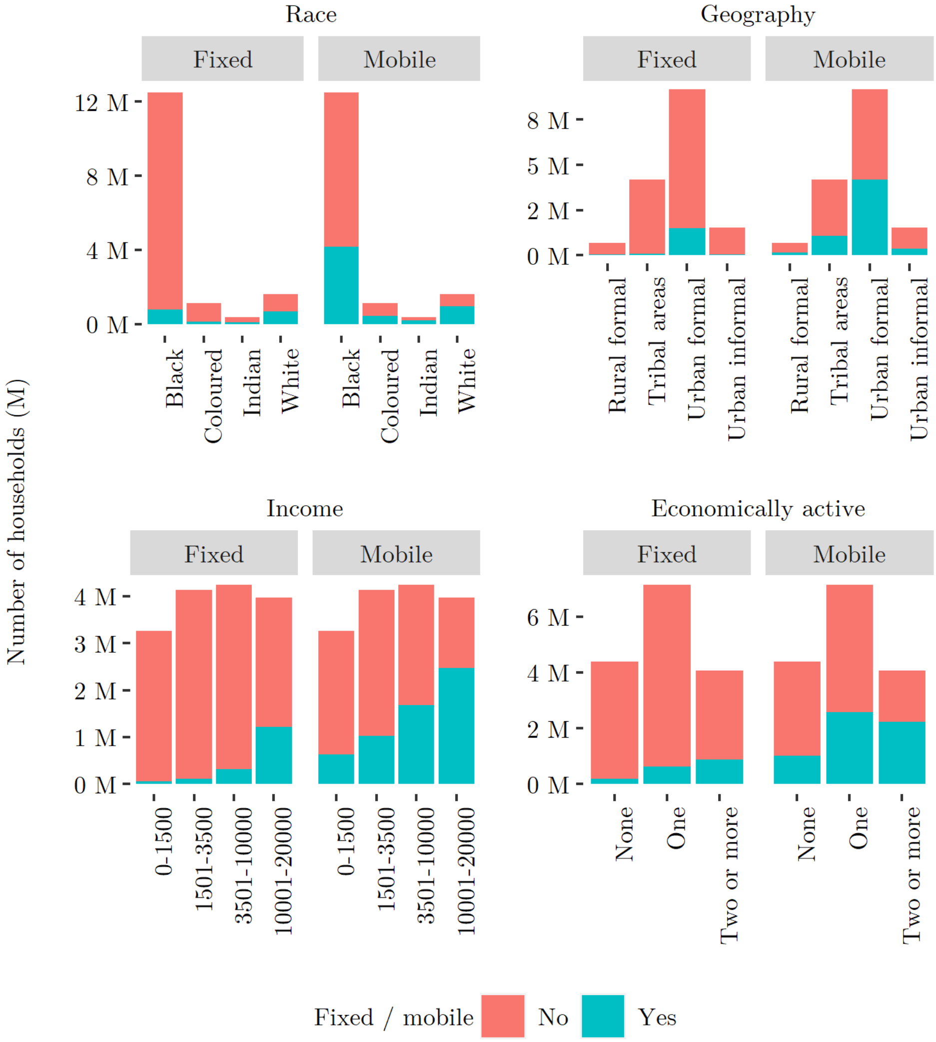


Figure produced using data from the International Telecommunications Union (ITU). Note that each dot is a country, and that the ITU estimate of internet access at home for South Africa is replaced by the estimate from Statistics South Africa. The ITU reports data for the year most recently available, which in most cases is 2016.

Figure 7: Digital divide (iii): a greater proportion of white, urban, high-income & the economically-active have fixed and mobile broadband connections in South Africa (2014)



Source: Statistics South Africa, General Household Surveys 2014. Notes: Income means monthly income in South African Rands. Economically active means number of members of household that are economically active (i.e. working or would accept a job).

A.3 Tables

Table 1: Fixed line and DSL penetration (2009-2014)

	2009	2010	2011	2012	2013	2014	Average
Telkom DSL lines (millions)	0.65	0.75	0.83	0.87	0.93	1.01	0.84
Telkom fixed lines (millions)	3.37	3.26	3.12	2.95	2.80	2.70	3.03
Statssa households (millions)	13.3	13.7	14.2	14.6	15.1	15.6	14.42
Fixed line household penetration	25.3%	23.8%	22.0%	20.2%	18.5%	17.3%	21.0%
DSL household penetration	4.87%	5.47%	5.84%	5.95%	6.17%	6.44%	5.8%

Sources: Telkom annual reports and Statistics South Africa (Stats SA) General Household Surveys.

Table 2: Fixed and mobile broadband speeds (Mbps) in South Africa (2009-2011)

	2009	2010	2011
Telkom ADSL 10Mbps		6.09	4.7
Cell C mobile HSPA+		7.21	3.3
Telkom ADSL 4 Mbps	2.95	2.91	3.54
Telkom mobile HSDPA	2.57	3.54	3.08
MTN mobile HSDPA	1.55	1.73	2.9
Vodacom mobile HSDPA	1.42	2.06	4.59
Telkom ADSL 512 / 1Mbps	0.42	0.41	0.74
Telkom ADSL 384	0.35	0.32	0.32

Source: https://mybroadband.co.za/. Note Telkom replaced the 512kbps ADSL product with 1Mbps in 2011. Cell C only introduced HSPA+ (3G) data in 2010.

Table 3: Network operator choices made by consumers in 2014 (number of observations in AMPS dataset)

	No fixed	Fixed voice only	Fixed voice & data	Total
No mobile	1,944	516	54	2,514
Mobile voice only				
Cell C	858	141	84	1,083
MTN	3,343	320	182	3,845
Telkom Mobile	52	12	10	74
Vodacom	3,502	550	319	4,371
Mobile voice & data				
Cell C	1,825	204	358	2,387
MTN	3,673	420	739	4,832
Telkom Mobile	101	20	50	171
Vodacom	4,046	601	1,094	5,741
Total	19,344	2,784	2,890	25,018

We test for substitution or complementarity in two areas: the first is for voice (the light gray cells, including for example where a consumer chooses a fixed voice only service and a mobile voice & data service) and the second is for voice & data, the area shaded dark gray.

Table 4: Fixed and mobile choices made by consumers 2009-2014

	2009		2010		2011		2012		2013		2014		Total
	N	%	N	%	N	%	N	%	N	%	N	%	N
Panel 1: Consumer chooses no mobile service													
No fixed	4,561	78	3,827	78	2,821	75	2,481	77	1,107	73	1,944	77	16,741
Fixed v	1,203	21	1,040	21	886	23	706	22	376	25	516	21	4,727
Fixed v&d	83	1	67	1	64	2	55	2	40	3	54	2	363
Total	5,847	100	4,934	100	3,771	100	3,242	100	1,523	100	2,514	100	21,831
Panel 2: Consumer chooses mobile voice only													
No fixed	11,633	71	11,737	74	11,740	77	10,656	79	4,789	80	7,755	83	58,310
Fixed v	3,076	19	2,748	17	2,300	15	1,783	13	775	13	1,023	11	11,705
Fixed v&d	1,730	11	1,435	9	1,305	9	1,006	7	411	7	595	6	6,482
Total	16,439	100	15,920	100	15,345	100	13,445	100	5,975	100	9,373	100	76,497
Panel 3: Consumer chooses mobile voice & data													
No fixed	1,224	63	2,426	70	3,851	73	5,467	71	3,449	71	9,645	73	26,062
Fixed v	558	29	815	24	986	19	1,185	15	637	13	1,245	9	5,426
Fixed v&d	171	9	202	6	473	9	1,091	14	748	15	2,241	17	4,926
Total	1,953	100	3,443	100	5,310	100	7,743	100	4,834	100	13,131	100	36,414
Total	24,239		24,297		24,426		24,430		12,332		25,018		134,742

Fixed v = Fixed voice, Fixed v&d = Fixed voice & data.

Table 5: **Choices of fixed & mobile services (%), by demographic variables (2009-2014)**

	0 none	1 mv	2 md	3 fv	4 fd	5 fv +mv	6 fv +md	7 fd +mv	8 fd +md	N
No computer	17	54	15	4	0	7	1	1	0	90,540
Computer	2	21	29	2	1	12	9	13	11	44,202
No Internet at work/school	14	46	18	4	0	9	4	4	3	121,203
Internet at work/school	2	23	36	1	0	7	9	13	10	13,539
Income <3,000	28	55	9	2	0	3	1	0	1	30,871
Income 3-7,999	14	53	17	4	0	8	2	1	1	37,743
Income 8-15,999	6	41	23	5	0	12	5	5	3	33,081
Income >15,999	2	24	28	3	1	11	9	13	10	33,047
Black	16	56	20	1	0	3	2	1	1	69,334
Coloured	19	36	17	6	0	12	5	2	3	19,398
Indian	6	22	17	11	1	19	12	7	6	8,981
White	4	28	19	6	1	16	6	12	8	37,029
Afrikaans	12	37	19	5	0	13	4	6	4	36,748
English	4	22	20	7	1	17	9	12	9	31,487
Zulu, Swazi, Ndebele	14	57	20	1	0	3	2	1	1	20,807
Xhosa	21	50	22	1	0	3	2	1	1	15,558
Sth, Tsw, Tsn, Ven, Oth	15	60	18	1	0	2	1	1	1	30,142
Age < 26 years	14	39	30	1	0	4	5	3	4	39,098
Age 26-50 years	10	49	21	1	0	6	4	5	4	59,851
Age 51-65 years	14	43	7	5	0	16	4	7	4	23,117
Age > 65 years	16	28	2	18	1	25	3	6	2	12,676
No or some High School	22	50	12	5	0	7	2	1	1	61,467
High School or more	4	38	25	3	0	10	6	8	6	73,275
Unemployed	16	43	17	5	0	9	3	3	2	80,866
Employed	7	44	22	1	0	8	5	7	5	53,876
Not self-employed	13	44	19	4	0	9	4	4	3	121,874
Self-employed	5	38	20	1	0	9	6	12	9	12,868
Rural	23	59	11	1	0	3	1	2	1	21,031
Towns	8	36	23	4	0	10	6	7	5	67,915
Cities	14	47	17	3	0	9	3	4	3	45,796
Home owned	13	42	17	4	0	10	5	5	4	101,812
Home rented	12	46	26	2	0	5	2	3	3	32,930
Male	14	41	20	3	0	8	4	5	4	67,171
Female	11	45	18	4	0	10	4	5	3	67,571
Household size <=2	11	42	17	5	0	12	3	6	4	45,520
Household size > 2	13	44	21	3	0	7	4	4	4	89,222
1 earner in household	15	50	18	3	0	7	2	3	2	62,430
2+ earners in household	10	38	21	4	0	10	5	6	5	72,312
<=1 cell in household	32	41	9	8	0	6	1	2	1	35,311
>1 cellphone in household	6	44	23	2	0	10	5	6	5	99,431
Not tech savvy	14	43	17	4	0	10	4	5	3	70,065
Tech savvy	11	44	22	3	0	7	4	5	4	64,677
Not occupied in services	15	44	18	4	0	9	3	3	3	97,046
Occupation in services	5	42	24	1	0	8	6	8	6	37,696
No work telephone	14	45	19	4	0	8	3	4	3	120,465
Work telephone	3	32	22	1	0	13	10	11	8	14,277
No console	14	47	17	4	0	9	3	4	2	117,234
Console (e.g. Xbox)	2	17	34	1	1	9	11	13	13	17,508
Total	12	43	19	4	0	9	4	5	4	134,742

The columns are: (0) no telecommunications services (0); (1) mobile voice (mv); (2) mobile voice and data (md); (3) fixed voice (fv); (4) fixed voice and data (fd); (5) mobile and fixed voice (mv+fv); (6) mobile voice and data and fixed voice (md+fv); (7) mobile voice and fixed voice and data (mv+fd); and (8) mobile and fixed voice and data (md+fd). The numbers reported are proportions of consumers from a particular demographic having made the choice indicated in the column title. The last column which shows the absolute number of consumers in that demographic. Note that proportions are not adjusted for fixed-line coverage nor survey weights.

Table 6: Fixed and mobile monthly bills per bundle (2009-2014)

	2009	2010	2011	2012	2013	2014	Average
Bundle 1: Mobile voice	210	182	158	151	138	113	155
Bundle 2: Mobile voice & data	624	514	626	613	597	636	615
Bundle 3: Fixed voice	135	145	150	158	167	176	151
Bundle 4: Fixed voice & data	653	659	688	687	777	792	712
Bundle 5: Fixed & mobile voice	300	284	264	251	242	224	266
Bundle 6: Mobile v&d, fixed v	759	662	782	764	755	800	769
Bundle 7: Fixed v&d, mobile v	1,172	1,155	1,099	1,051	1,031	1,008	1,103
Bundle 8: Fixed & mobile v&d	1,545	1,591	1,547	1,534	1,622	1,622	1,592

These numbers represent averages across consumer types —prepaid, as well as low, medium, and high post-paid—and across operators for mobile services. There is only one provider for fixed-line services.

Table 7: Fixed and mobile data characteristics, 2009-2014

	2009	2010	2011	2012	2013	2014	Average
Mobile data (GB)							
Low mobile data	0.02	0.04	0.06	0.08	0.15	0.15	0.08
Medium mobile data	0.15	0.28	0.33	0.39	0.88	0.88	0.54
High mobile data	1.68	1.42	2.79	2.69	3.50	5.00	2.99
Fixed data speeds							
Low fixed data	0.38	0.38	0.38	0.38	0.38	2.05	0.66
Medium fixed data	0.38	0.38	0.38	0.38	1.02	4.10	1.03
High fixed data	4.10	4.10	4.10	4.10	4.10	10.24	5.02

Table 8: Control function estimation results

	Co-efficient	(SE)
Termination cost (fixed, mobile voice)	0.95***	(0.02)
Sites (mobile data)	3.66***	(0.35)
Electricity (fixed data)	6.60***	(0.06)
Mobile minutes	0.48***	(0.04)
Mobile data - GB	122.20***	(1.52)
Cell C	-29.26**	(9.05)
MTN	63.64***	(9.21)
Telkom	29.60**	(9.69)
Vodacom	17.00+	(9.19)
Fixed line - Mbps	52.25***	(0.93)
Fixed line	156.23***	(2.75)
Mobile postpaid - Medium voice	0.00	(8.17)
Mobile postpaid - High voice	0.00	(8.17)
Cell C prepaid	48.73***	(7.96)
Cell C postpaid medium voice	-9.82	(18.18)
Cell C postpaid high voice	221.79***	(37.09)
MTN prepaid	-46.33***	(7.96)
MTN postpaid medium voice	159.38***	(18.16)
MTN postpaid high voice	659.18***	(37.06)
Telkom prepaid	-0.27	(9.18)
Telkom Mobile postpaid medium voice	0.55	(18.73)
Telkom Mobile postpaid high voice	231.74***	(37.34)
Vodacom prepaid voice	-2.23	(7.96)
Vodacom postpaid medium voice	70.20***	(18.17)
Vodacom postpaid high voice	393.06***	(37.08)
Mobile internet medium usage	0.00	(8.17)
Mobile internet high usage	0.00	(8.17)
Cell C medium internet usage	13.09	(10.03)
Cell C high internet usage	6.16	(10.14)
MTN medium internet usage	30.21**	(10.03)
MTN high internet usage	23.53*	(10.17)
Telkom medium internet usage	13.34	(10.83)
Telkom high internet usage	57.95***	(11.15)
Vodacom medium internet usage	26.58**	(10.03)
Vodacom high internet usage	4.66	(10.47)
2010	3.81	(4.38)
2011	-46.26***	(4.28)
2012	-51.67***	(4.54)
2013	-61.84***	(4.87)
2014	-144.59***	(5.33)
Constant	52.18***	(6.44)
Number of obs	11,050	
R-squared	0.96	

+ $p<0.10$, * $p<0.05$, ** $p<0.01$, *** $p<0.001$

Table 9: Estimation results

Main effects	(1)	Interactions	(2) Fixed service (F)	(3) Mobile service (M)	(4) FM Voice (Γ_{FMV})	(5) FM Voice, data (Γ_{FMVD})
	Coeff. (SE)	Demographics	Coeff. (SE)	Coeff. (SE)	Coeff. (SE)	Coeff. (SE)
Monthly bill	-0.006***	Γ (stand-alone)			0.933***	-0.631*
	(0.000)				(0.194)	(0.261)
Minutes	0.137	Computer	0.570***	0.256***	0.215***	1.366***
	(4.378)		(0.054)	(0.038)	(0.055)	(0.089)
Mobile data - GB	1.328***	I'net work/sch.	0.201	0.539***	-0.102	-0.016
	(0.008)		(0.125)	(0.077)	(0.126)	(0.132)
Telkom Mobile	-10.028	Cities	0.090	0.073**	0.039	0.073
	(131.343)		(0.101)	(0.027)	(0.103)	(0.141)
Vodacom	-5.941	Towns	0.391***	0.087**	-0.102	-0.123
	(131.343)		(0.100)	(0.028)	(0.102)	(0.138)
Cell C	-7.155	Age 26-50	0.418***	0.339***	-0.332***	-0.363***
	(131.343)		(0.066)	(0.026)	(0.069)	(0.083)
MTN	-5.672	Age 51-65	1.306***	0.073*	-0.504***	-0.754***
	(131.343)		(0.065)	(0.031)	(0.067)	(0.090)
Fixed line	-1.994***	Age 66+	2.167***	-0.318***	-0.574***	-1.242***
	(0.187)		(0.068)	(0.039)	(0.073)	(0.117)
Fixed line - Mbps	1.863***	High school+	0.536***	0.871***	-0.300***	-0.023
	(0.017)		(0.044)	(0.025)	(0.046)	(0.071)
Fixed voice *	0.272***	Rent	-0.836***	0.150***	0.001	0.403***
work telephone	(0.027)		(0.051)	(0.025)	(0.054)	(0.070)
Fixed data *	0.849***	Working	-0.265**	0.534***	-0.084	-0.047
console	(0.029)		(0.087)	(0.036)	(0.090)	(0.116)
Residuals (CF)	0.008***	Self-employed	0.247*	0.076	0.036	0.282*
	(0.000)		(0.100)	(0.051)	(0.102)	(0.113)
		Coloured	1.239***	-0.309***	-0.320*	-0.951***
			(0.144)	(0.071)	(0.150)	(0.178)
		Indian	1.794***	-0.285***	-0.590***	-1.341***
			(0.149)	(0.085)	(0.155)	(0.180)
		White	1.286***	0.251***	-0.419**	-0.842***
			(0.145)	(0.074)	(0.150)	(0.171)
		Income 3-8	0.366***	0.056*	-0.234***	-0.915***
			(0.058)	(0.025)	(0.065)	(0.126)
		Income 8-16	0.623***	0.059+	-0.444***	-0.844***
			(0.065)	(0.035)	(0.072)	(0.114)
		Income 16+	0.893***	0.188***	-0.639***	-0.655***
			(0.082)	(0.051)	(0.087)	(0.121)
		Afrikaans	-0.705***	-0.223***	0.085	0.000
			(0.057)	(0.045)	(0.060)	(0.075)
		Zulu+	0.041	0.135+	-0.348*	-0.478*
			(0.160)	(0.072)	(0.166)	(0.195)
		Xhosa	-0.511**	-0.198**	0.137	-0.107
			(0.168)	(0.073)	(0.175)	(0.212)
		Sesotho+	-0.275+	0.090	-0.282+	-0.306+
			(0.141)	(0.071)	(0.146)	(0.174)
		Female	0.578***	0.503***	-0.453***	-0.373***
			(0.039)	(0.021)	(0.041)	(0.055)
		Hh size	-0.166**	-0.688***	0.064	0.065
			(0.052)	(0.027)	(0.054)	(0.070)
		Hh earners	0.274***	-0.472***	-0.056	-0.203**
			(0.044)	(0.024)	(0.046)	(0.064)
		Hh cells	-0.294***	2.190***	0.262***	0.471***
			(0.047)	(0.025)	(0.051)	(0.092)
		Tech savvy	-0.018	0.115***	-0.028	0.009
			(0.039)	(0.020)	(0.040)	(0.054)
		Services occup.	0.074	0.232***	0.059	0.183
			(0.093)	(0.040)	(0.096)	(0.115)
		2010	-0.095***	0.180***		
			(0.026)	(0.027)		
		2011	-0.227***	0.308***		
			(0.027)	(0.028)		
		2012	-0.303***	0.415***		
			(0.027)	(0.029)		
		2013	-0.477***	0.513***		
			(0.034)	(0.037)		
		2014	-1.412***	0.625***		
			(0.031)	(0.032)		

+ p<0.10, * p<0.05, ** p<0.01, *** p<0.001

Table 10: Distribution of fixed and mobile (Γ_{ir})

	(1) Fixed & mobile voice (mean)	(2) Fixed & mobile voice (SE)	(3) Fixed & mobile voice & data (mean)	(4) Fixed & mobile voice & data (SE)	(5) N
2009	-0.11	0.51	-1.62	0.95	24,239
2010	-0.14	0.51	-1.64	0.95	24,297
2011	-0.15	0.52	-1.62	0.95	24,426
2012	-0.16	0.52	-1.61	0.95	24,430
2013	-0.18	0.53	-1.61	0.96	12,332
2014	-0.18	0.51	-1.62	0.98	25,018

For each individual, we add the Γ_{ir} for each main effect and each control (interaction). The columns show the average and standard deviations for the (Γ_{ir}), for voice (columns 1 and 2) and voice and data (columns 3 and 4) for each year. The total number of survey respondents in the year is shown in column 5.

Table 11: Distribution of fixed and mobile Γ_{ir}

	(1) Fixed & mobile voice (mean)	(1) Fixed & mobile voice (SE)	(3) Fixed & mobile voice & data (mean)	(4) Fixed & mobile voice & data (SE)	(5) N
No computer	-0.10	0.52	-2.00	0.83	90,540
Computer	-0.27	0.48	-0.85	0.69	44,202
No Internet at work/school	-0.12	0.51	-1.68	0.95	121,203
Internet at work/school	-0.40	0.48	-1.06	0.84	13,539
Income <3,000	0.24	0.44	-1.28	0.77	30,871
Income 3-7,999	-0.04	0.44	-2.10	0.87	37,743
Income 8-15,999	-0.30	0.44	-1.80	0.98	33,081
Income >15,999	-0.50	0.42	-1.22	0.89	33,047
Black	0.06	0.47	-1.33	0.80	69,334
Coloured	-0.07	0.41	-2.05	0.88	19,398
Indian	-0.59	0.41	-2.28	0.97	8,981
White	-0.48	0.42	-1.78	1.06	37,029
Afrikaans	-0.25	0.45	-1.92	0.99	36,748
English	-0.46	0.46	-1.79	1.10	31,487
Zulu, Swazi, Ndebele	-0.10	0.42	-1.53	0.78	20,807
Xhosa	0.43	0.44	-1.17	0.77	15,558
Sth, Tsw, Tsn, Ven, Oth	-0.05	0.44	-1.38	0.77	30,142
Age < 26 years	0.25	0.44	-1.08	0.78	39,098
Age 26-50 years	-0.24	0.44	-1.51	0.79	59,851
Age 51-65 years	-0.41	0.45	-2.11	0.82	23,117
Age > 65 years	-0.51	0.44	-2.90	0.81	12,676
No or some High School	0.11	0.47	-1.76	0.94	61,467
High School or more	-0.37	0.45	-1.51	0.96	73,275
Unemployed	-0.06	0.54	-1.74	1.01	80,866
Employed	-0.28	0.45	-1.45	0.84	53,876
Not self-employed	-0.14	0.52	-1.66	0.96	121,874
Self-employed	-0.30	0.44	-1.21	0.85	12,868
Rural	0.07	0.50	-1.58	0.75	21,031
Towns	-0.28	0.51	-1.66	1.02	67,915
Cities	-0.07	0.48	-1.58	0.95	45,796
Home owned	-0.15	0.53	-1.72	0.95	101,812
Home rented	-0.16	0.46	-1.33	0.93	32,930
Male	0.07	0.47	-1.41	0.94	67,171
Female	-0.37	0.46	-1.83	0.93	67,571
Household size <=2	-0.31	0.50	-1.84	1.04	45,520
Household size > 2	-0.07	0.50	-1.51	0.89	89,222
1 earner in household	-0.06	0.53	-1.54	0.92	62,430
2+ earners in household	-0.23	0.49	-1.69	0.98	72,312
<=1 cell in household	-0.21	0.52	-2.04	0.97	35,311
>1 cellphone in household	-0.13	0.51	-1.47	0.91	99,431
Not tech savvy	-0.16	0.52	-1.71	0.97	70,065
Tech savvy	-0.14	0.51	-1.53	0.93	64,677
Not occupied in services	-0.08	0.52	-1.72	0.98	97,046
Occupation in services	-0.35	0.44	-1.38	0.84	37,696
Entire sample	-0.15	0.52	-1.62	0.96	134,742

For each individual, we add the Γ_{ir} for each main effect and each control (interaction). The columns show the average and standard deviations for the (Γ_{ir}), for voice (columns 1 and 2) and voice and data (columns 3 and 4) for each demographic variable. The total number of survey respondents belonging to the demographic variable category is shown in column 5, and the total observations in respect of columns 1-4 are shown in the bottom row.

Table 12: **Counterfactual scenarios (2014): mobile data price reduced by 30% & full fixed coverage**

	Mobile data penetration (%)			Fixed data penetration (%)		
	(1) Base	(2) -30% mobile data price	(3) 100% fixed	(4) Base	(5) -30% mobile data price	(6) 100% fixed
No computer	53.3	56.4	52.9	1.5	1.5	2.9
Computer	75.1	80.1	75.1	26.3	26.1	27.1
No Internet at work/school	57.4	60.8	57.0	6.7	6.7	8.0
Internet at work/school	76.4	81.0	76.3	16.7	16.6	17.2
Income <3,000	46.2	48.9	45.9	3.9	3.8	5.7
Income 3-7,999	54.5	57.7	54.1	1.9	1.8	3.4
Income 8-15,999	63.6	67.6	63.4	6.8	6.6	7.7
Income >15,999	73.9	78.7	73.9	21.8	21.6	22.2
Black	57.2	60.4	56.8	3.1	3.1	4.6
Coloured	56.8	60.9	56.6	10.6	10.3	11.4
Indian	62.8	67.7	62.8	28.1	27.6	28.3
White	67.7	72.3	67.7	30.9	30.5	30.9
Afrikaans	60.2	64.4	60.1	15.2	14.9	15.7
English	68.0	72.8	67.9	29.0	28.7	29.2
Zulu, Swazi, Ndebele	57.5	60.7	57.0	3.0	3.0	4.7
Xhosa	53.1	56.3	52.8	2.3	2.3	3.9
Sth, Tsw, Tsn, Ven, Oth	57.5	60.7	57.2	2.5	2.5	3.9
Age < 26 years	66.7	71.2	66.6	5.1	5.0	6.0
Age 26-50 years	62.3	65.9	62.1	7.2	7.2	8.1
Age 51-65 years	44.2	46.5	43.7	8.9	8.8	10.8
Age > 65 years	31.5	33.2	30.5	12.4	12.2	16.3
No or some High School	47.2	49.9	46.7	2.5	2.4	4.2
High School or more	71.0	75.4	70.9	12.7	12.6	13.5
Unemployed	54.7	58.0	54.3	5.4	5.3	6.9
Employed	65.0	68.8	64.8	10.7	10.6	11.5
Not self-employed	57.9	61.4	57.6	6.3	6.2	7.6
Self-employed	63.9	67.6	63.7	18.1	18.0	19.1
Rural	50.0	52.8	49.5	0.7	0.7	2.8
Towns	64.8	68.9	64.6	12.7	12.5	13.4
Cities	59.9	63.6	59.7	7.9	7.8	8.8
Home owned	57.5	60.9	57.1	7.4	7.3	8.8
Home rented	62.1	65.8	62.0	6.7	6.6	7.2
Male	57.8	61.4	57.6	7.7	7.7	8.8
Female	58.9	62.3	58.5	6.8	6.7	8.3
Household size <=2	55.1	58.4	54.8	9.1	9.0	10.4
Household size > 2	59.3	62.9	59.0	6.7	6.6	8.0
1 earner in household	55.9	59.2	55.7	4.6	4.6	5.8
2+ earners in household	60.1	63.8	59.8	9.2	9.1	10.5
<=1 cell in household	38.4	40.9	38.0	4.1	4.0	6.0
>1 cellphone in household	62.8	66.6	62.5	8.0	7.9	9.1
Not tech savvy	55.0	58.3	54.7	6.8	6.7	8.2
Tech savvy	61.8	65.6	61.6	7.8	7.7	8.9
Not occupied in services	55.1	58.4	54.7	5.4	5.3	6.8
Occupation in services	69.1	73.2	68.9	13.4	13.3	14.2
Total voice and data	58.4	61.9	58.1	7.3	7.2	8.5

In column (1) base scenario probabilities are shown for mobile broadband. Column (2) shows mobile broadband penetration if mobile data prices were reduced by 10% and column (3) assuming 100% fixed-line coverage. In column (4) base scenario probabilities are shown for fixed broadband. Column (5) shows fixed penetration if mobile data prices were reduced by 10% and column (6) assuming 100% fixed-line coverage.

Table 13: Counterfactual scenarios (2014): all individuals have a computer and Internet access at work/school

	Mobile data penetration (%)			Fixed data penetration (%)		
	(1) Base	(2) Comp	(3) Work/School	(4) Base	(5) Comp	(6) Work/School
No computer	53.3	54.4	55.1	1.5	3.0	1.7
Computer	75.1	75.1	75.6	26.3	26.3	27.3
No Internet at work/school	57.4	58.2	58.9	6.7	7.9	7.1
Internet at work/school	76.4	76.7	76.4	16.7	18.3	16.7
Income <3,000	46.2	47.6	48.9	3.9	4.4	4.0
Income 3-7,999	54.5	55.4	56.2	1.9	2.6	2.0
Income 8-15,999	63.6	64.2	64.6	6.8	8.5	7.2
Income >15,999	73.9	74.4	74.4	21.8	23.8	22.7
Black	57.2	58.0	58.8	3.1	3.9	3.3
Coloured	56.8	57.7	58.8	10.6	12.7	11.2
Indian	62.8	63.5	63.7	28.1	31.5	28.9
White	67.7	68.1	68.2	30.9	33.3	31.8
Afrikaans	60.2	60.9	61.7	15.2	17.2	15.9
English	68.0	68.5	68.6	29.0	31.8	29.9
Zulu, Swazi, Ndebele	57.5	58.3	58.9	3.0	3.9	3.2
Xhosa	53.1	54.2	55.4	2.3	2.9	2.5
Sth, Tsw, Tsn, Ven, Oth	57.5	58.3	59.0	2.5	3.2	2.7
Age < 26 years	66.7	67.5	68.2	5.1	5.9	5.4
Age 26-50 years	62.3	63.0	63.4	7.2	8.3	7.6
Age 51-65 years	44.2	45.2	46.2	8.9	10.4	9.3
Age > 65 years	31.5	32.8	34.5	12.4	14.6	12.8
No or some High School	47.2	48.3	49.6	2.5	3.2	2.7
High School or more	71.0	71.4	71.5	12.7	14.3	13.2
Unemployed	54.7	55.6	56.5	5.4	6.4	5.6
Employed	65.0	65.5	65.8	10.7	11.9	11.1
Not self-employed	57.9	58.7	59.4	6.3	7.4	6.6
Self-employed	63.9	64.5	64.7	18.1	19.6	18.7
Rural	50.0	51.1	52.2	0.7	0.8	0.7
Towns	64.8	65.4	65.8	12.7	14.6	13.2
Cities	59.9	60.7	61.3	7.9	9.4	8.3
Home owned	57.5	58.3	59.0	7.4	8.6	7.7
Home rented	62.1	62.9	63.4	6.7	7.7	7.0
Male	57.8	58.7	59.5	7.7	8.8	8.1
Female	58.9	59.6	60.2	6.8	8.1	7.2
Household size <=2	55.1	56.0	56.7	9.1	10.5	9.5
Household size > 2	59.3	60.1	60.8	6.7	7.8	7.0
1 earner in household	55.9	56.9	57.6	4.6	5.4	4.8
2+ earners in household	60.1	60.9	61.5	9.2	10.6	9.6
<=1 cell in household	38.4	40.2	42.3	4.1	4.9	4.2
>1 cellphone in household	62.8	63.4	63.8	8.0	9.2	8.4
Not tech savvy	55.0	55.9	56.7	6.8	8.0	7.1
Tech savvy	61.8	62.6	63.1	7.8	8.9	8.1
Not occupied in services	55.1	56.0	56.9	5.4	6.4	5.7
Occupation in services	69.1	69.6	69.6	13.4	14.9	13.9
Total voice and data	58.4	59.2	59.9	7.3	8.4	7.6

In column (1), base scenario probabilities are shown for mobile broadband. Column (2) shows mobile broadband penetration if all individuals had a computer and column (3) if all individuals had access to Internet at work/school. In column (4), base scenario probabilities are shown for fixed broadband. Column (5) shows fixed penetration if all individuals had a computer and column (6) if all individuals had access to Internet at work/school.

Table 14: Counterfactual scenarios (2014): cumulative effects

	Mobile data penetration (%)			Fixed data penetration (%)		
	(1) Base	(2) Comp, Work/ School	(3) Fixed, Comp, W/S	(4) Base	(5) Com, Work/ School	(6) Fixed, Comp, W/S
No computer	53.3	56.0	55.6	1.5	3.3	6.9
Computer	75.1	75.6	75.5	26.3	27.3	28.2
No Internet at work/school	57.4	59.6	59.3	6.7	8.3	11.4
Internet at work/school	76.4	76.7	76.7	16.7	18.3	19.4
Income <3,000	46.2	50.0	49.7	3.9	4.6	9.1
Income 3-7,999	54.5	56.8	56.2	1.9	2.8	6.4
Income 8-15,999	63.6	65.1	64.8	6.8	9.1	11.3
Income >15,999	73.9	74.8	74.7	21.8	24.8	25.7
Black	57.2	59.4	59.1	3.1	4.2	7.8
Coloured	56.8	59.5	59.2	10.6	13.5	15.1
Indian	62.8	64.4	64.3	28.1	32.5	32.8
White	67.7	68.6	68.6	30.9	34.4	34.4
Afrikaans	60.2	62.3	62.1	15.2	18.1	19.2
English	68.0	69.1	69.1	29.0	32.8	33.3
Zulu, Swazi, Ndebele	57.5	59.5	59.0	3.0	4.2	8.1
Xhosa	53.1	56.3	56.0	2.3	3.2	7.0
Sth, Tsw, Tsn, Ven, Oth	57.5	59.6	59.3	2.5	3.4	6.9
Age < 26 years	66.7	68.8	68.7	5.1	6.3	8.7
Age 26-50 years	62.3	64.0	63.8	7.2	8.8	11.1
Age 51-65 years	44.2	47.0	46.4	8.9	10.9	15.1
Age > 65 years	31.5	35.6	34.2	12.4	15.1	21.8
No or some High School	47.2	50.5	50.0	2.5	3.5	7.3
High School or more	71.0	71.9	71.8	12.7	15.0	17.0
Unemployed	54.7	57.3	56.9	5.4	6.8	10.3
Employed	65.0	66.3	66.2	10.7	12.5	14.5
Not self-employed	57.9	60.1	59.8	6.3	7.8	10.9
Self-employed	63.9	65.2	65.1	18.1	20.4	22.8
Rural	50.0	53.0	52.5	0.7	0.8	5.8
Towns	64.8	66.3	66.1	12.7	15.3	16.9
Cities	59.9	61.9	61.7	7.9	10.0	12.2
Home owned	57.5	59.7	59.3	7.4	9.0	12.3
Home rented	62.1	64.0	64.0	6.7	8.2	9.7
Male	57.8	60.2	59.9	7.7	9.2	11.8
Female	58.9	60.8	60.4	6.8	8.5	11.9
Household size <=2	55.1	57.5	57.2	9.1	10.9	13.7
Household size > 2	59.3	61.4	61.1	6.7	8.2	11.3
1 earner in household	55.9	58.3	58.1	4.6	5.8	8.9
2+ earners in household	60.1	62.1	61.7	9.2	11.1	14.0
<=1 cell in household	38.4	43.9	43.4	4.1	5.1	9.2
>1 cellphone in household	62.8	64.2	63.9	8.0	9.7	12.4
Not tech savvy	55.0	57.4	57.0	6.8	8.4	11.6
Tech savvy	61.8	63.7	63.4	7.8	9.3	12.1
Not occupied in services	55.1	57.6	57.2	5.4	6.8	10.1
Occupation in services	69.1	70.0	69.9	13.4	15.5	17.5
Total voice and data	58.4	60.5	60.2	7.3	8.9	11.8

In column (1) base scenario probabilities are shown for mobile broadband. Column (2) shows mobile broadband penetration if computers and internet at work and school were available to all, and column (3) assuming the latter and 100% fixed-line coverage. In column (4) base scenario probabilities are shown for fixed broadband. Column (5) shows fixed penetration if computers and internet at work and school were available to all, and column (6) assuming the latter and 100% fixed-line coverage.

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