# The impact of heterogenous consumer preferences on welfare outcomes of government interventions

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by

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## Dedication

This work is dedicated to my wife, Susan, without whom this project would not have been possible, and to my parents Alex and Shelley, for all of their support.

## Acknowledgements

I would like to thank my supervisors, Lukasz Grzybowski, Lawrence Edwards and Simon Roberts, for their comments and support throughout this process. Lukasz Grzybowski in particular provided extensive support, comments and suggestions and coauthored two of the chapters of my thesis, and for this I am very grateful.

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A number of people also provided helpful comments and useful suggestions during the course of my research. I am grateful to the editors and reviewers of Telecommunications Policy, Economic Inqury, and the International Journal of Industrial Organization for their comments and suggestions. The examiners of my thesis, Willem Boshoff, Toker Doganoglu and Christine Zulehner, also provided helpful comments and suggestions. Discussions with my colleagues at Acacia Economics, particularly Sha'ista Goga and Genna Robb, enriched my research. Students and staff at the Universities of Cape Town, Stellenbosch and Johannesburg also provided helpful comments at seminars. I am also grateful to participants at: the CSAE conference in 2019; the 11th Paris Conference on Digital Economics hosted by Telecom Paristech in 2019; Workshop on Platforms, E-commerce and Digital Economics hosted by CREST – Telecom ParisTech in 2019; International Telecommunications Society conferences in Cambridge in 2016 and Lusaka in 2018 (and for comments received at the ITS PhD seminar in Cambridge in 2016); the annual Competition Commission of South Africa conferences between 2015 and 2018; the African Competition and Economic Regulation conferences in 2015, 2016 and 2018.

## Declaration

I confirm that I have been granted permission by the University of Cape Town's Doctoral Degrees Board to include the following publications in my PhD thesis, and where co-authorships are involved, my co-authors have agreed that I may include the publications:

a. Hawthorne, R. (2018). The effects of lower mobile termination rates in South Africa. Telecommunications Policy, 42(5), 374-385.
b. Hawthorne, R. & Grzybowski, L. (2019). Benefits of regulation vs. competition where inequality is high: The case of mobile telephony in South Africa. (Under review.)
c. Hawthorne, R. & Grzybowski, L. (2019). Substitution between fixed and mobile data amidst high levels of poverty and inequality. (Under review.)

Please note that the last paper's title has changed since the approval from the DDB's office was received, from "Can mobile broadband allow developing countries to 'leapfrog' developed countries? Evidence on bridging the 'digital divide' in Africa." The substance of the contribution remains the same.

My contributions to each of the publications are as follows. The first contribution, titled "The effects of lower mobile termination rates in South Africa", was authored solely by myself and published in Telecommunications Policy. Lukasz Grzybowski supervised this research and made important comments and suggestions, including on using the data to comment on the impact of regulation. I contributed almost all of the work on this paper.

The second paper is titled "Benefits of regulation vs. competition where inequality is high: The case of mobile telephony in South Africa." I co-authored this paper with my supervisor, Lukasz Grzybowski. I collected a substantial proportion of the voice service pricing data, cleaned the price and survey (AMPS) data, developed substantial code in Stata in order to clean the data and run the estimations and subsequent simulations, produced all of the tables and figures in the paper and contributed substantially to the write-up of the paper.

The third contribution, on "Substitution between fixed and mobile data amidst high levels of poverty and inequality", is again co-authored with with my supervisor, Lukasz Grzybowski. I collected a substantial amount of the pricing data (augmenting the dataset described above for my second contribution), and again cleaned and price and survey data, which required significant additional work due to evaluating internet services (in addition to voice). Again, I developed significant Stata code to be able to do so, and in order to run the estimations and process the post-estimation results, including running simulations. I produced all of the tables and figures in the paper and contributed substantially to the write-up of the paper.

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## Abstract

Heterogeneity in the demand for telecommunications services in South Africa is investigated here in three contributions. The results of this research show that government interventions in the telecommunications sector over the last decade have had significantly different effects on different groups of consumers, and in particular that the rich have benefited more than the poor. Heterogeneous consumer preferences are especially interesting to study in highly unequal developing countries like South Africa, where the discriminatory policies implemented during apartheid have resulted in a deeply divided society. For example, the results of the first contribution show how the regulation of mobile termination rates (MTRs, which were reduced by 90% between 2009 and 2017) accounted for around 60% of the reduction in quality-adjusted postpaid prices in South Africa, used mainly by high-income consumers. However, MTR reductions accounted for only 30% of the reduction in prepaid prices, typically used by poor consumers. Quality-adjusted prices and the effects of lower MTRs have previously been studied in developed countries where prepaid does not matter as much, and these studies have typically used average, aggregate price data or data on an individual operator. In this contribution, the effects of lower MTRs are evaluated using a unique dataset on 2,773 operator-level mobile tariffs over the period between 2009 and 2017 in a developing country, South Africa. The variation in prices at the operator level is further exploited to show that on-net and off-net prices converged as a result of lower termination rates. This reduces the ability of firms with market power to use high MTRs to generate tariff-mediated network effects to exclude rivals.

In the second contribution, the effects of consumer heterogeneity are further explored by developing a structural model of demand and supply in a discrete-choice framework. We test for the distributional effects of regulation and entry in the mobile telecommunications sector in a highly unequal country, South Africa. Using six waves of a consumer survey of over 134,000 individuals between 2009-2014, we estimate a discrete-choice model allowing for individual-specific price-responsiveness and preferences for network operators. Next, we use a demand and supply equilibrium framework to simulate prices and the distribution of welfare without entry and mobile termination rate regulation. We find that regulation benefits consumers significantly more than entry does, and that high-income consumers and city-dwellers benefit more in terms of increased consumer surplus.

In the third contribution, we exploit the discriminatory roll-out of fixed-lines during apartheid to Whites-only areas to study fixed and mobile substitution, using the same survey data. In our discrete-choice model, individuals choose fixed or mobile voice and data services in a framework that allows them to be substitutes or complements. We find that voice services are complements on average but data services are substitutes. However, many consumers see data services as complements. Our results show that having a computer and access to an internet connection at work or school are more important than reducing mobile data prices by 10% in driving broadband penetration.

# Table of Contents

## List of Figures

# List of Tables

# 1 Introduction

There are significant differences in preferences for telecommmunications services among consumers (see, for example, Grzybowski, 2014). However, there is very little research on how consumer heterogeneity affects the outcomes of government interventions in the sector. This question is studied here in three contributions. In the first contribution, 2,773 retail prices were collected in order to assess the impact of the regulation of mobile termination rates (MTRs) between 2009 and 2017. The results show that MTRs explained significantly more of the reductions in postpaid prices than prepaid prices, reflecting differences in the impact of MTR regulations on rich (postpaid) and poor (prepaid) consumers. In the second contribution, heterogeneity in the consumer welfare effects of entry and MTR regulation are considered using a survey of 134,000 consumers between 2009 and 2014. It turns out that entry and regulation benefited rich consumers more than poor consumers, even though we would expect poor consumers to benefit the most from government interventions. In the third contribution, we show how the discriminatory rollout of fixed lines during apartheid to White households is perpetuating the 'digital divide' in respect of broadband services. We use a discrete choice model to study whether fixed and mobile services are subtitutes or complements, using the same survey dataset as above. We find that fixed and mobile services are complements for consumers that own a computer and are weaker substitutes for the employed, self-employed and for consumers that have an internet connection at work or school. These characteristics describe higher-income and often White households, who continue to benefit from the discriminatory rollout of fixed-lines during apartheid.

These questions and contributions are important because telecommunications services have a significant impact on economic development. Research on the impact of the expansion of these services at the country level shows significant transformations of economies and societies. For example, Roller and Waverman (2001) show that the expansion of telecommunications services leads to higher economic growth of between approximately 0.5%-1.5%, and that growth rates are higher if access is close to universal. Qiang et al. (2009) find that a 10% increase in broadband penetration results in a 1.21 percentage point increase in economic growth in developed countries and a 1.38 percentage point increase in developing countries. Similarly, Czernich et al. (2011) show that a 10% expansion of broadband services leads to a 0.9-1.5 percentage point increase in economic growth. Hjort and Poulsen (forthcoming) show that expanding access to high-speed internet as subsea cables landed in a number of African countries, including South Africa, boosted the number of businesses created, reduced unemployment and boosted productivity. The benefits from the expansion of telecommunications services are not limited to internet access, and considerable consumer gains continue to be reported in respect of the expansion of voice services in developing countries (see, for example, Björkegren, 2018). Access to telecommunications services therefore have important positive developmental outcomes.

The state has an important role to play in the roll-out of telecommunications services by, for example, issuing licences, subsiding network roll-out and regulating prices. However, there is very little research on the effects of such interventions using granular data on consumers. In addition, there is very little research on consumer choices of telecommunications services in developing countries like South Africa, where most people use mobile services for communications. This study is also of interest in developed countries, where mobile broadband is growing significantly and may become a substitute for fixed-line broadband in future as technology progresses. This has important consequences in many European Union countries, for example, where incumbent fixed-line network operators face substantial access and price regulation (see, for example, Cardona et al., 2009).

The evaluation of individual-level data may also be of interest to regulators and policymakers concerned about the role that regulation may have on inequality (see, for example, Baker and Salop, 2015). Government interventions can have significant distributional consequences. For example, Wodon and Zaman (2009) find that lower food prices would benefit non-poor consumers at the expense of poor producers. Argent and Begazo (2015) show that reducing sugar and maize prices by 20% could result in a reduction in poverty of 1.5% and 1.8% respectively by making markets more competitive in Kenya.

The literature on the assessment of relevant markets and the impact of competition and regulation largely focuses on developed countries using aggregate, country-level data. In respect of papers that assess individual or household-level data, there are relatively few papers and these largely consider data on developed countries. For example, Rodini et al. (2003) and Ward and Woroch (2010) evaluate fixed and mobile access substitution using data on U.S. households. In another paper, Suárez and García-Mariñoso (2013) use panel data on Spanish households for the years between 2004 and 2009 to analyse substitution from fixed to mobile access services.

But the effects of consumer heterogeneity on the welfare outcomes of government interventions have not been emphasized previously in the literature. This is especially important in countries like South Africa that have extremely high levels of inequality due to the discriminatory policies employed during apartheid, and therefore where the effects of government intervention may be very different in different segments of society. For example, the third contribution studies the effect of rolling out fixed-lines to only White households during apartheid and the impact this has today on perpetuating the 'digital divide' between largely rich, White people who are able to use fixed-line broadband for high-usage applications and largely poor, Black people who have to rely on expensive, limited use mobile data.

There are also no papers that I am aware of that provide a structural model of demand and supply to assess the welfare effects of competition and regulation. Furthermore, telecommunications prices are not typically analysed at the operator-level over time due to lack of data. This is a limitation because telecommunications bundles change over time, typically improving in quality. An important contribution here is the development of a unique dataset on 2,773 telecommunications service prices over the years between 2009 and 2017 on a range of fixed and mobile voice and data services offered by each of the network operators in South Africa. In addition, developed countries typically have full-coverage fixed-line networks while developing countries have no or limited fixed-line coverage. The rollout of fixed-lines to Whites-only areas during apartheid allows us to assess fixed and mobile substitution in a developing-country setting.

This thesis is divided into three contributions, which can be described in more detail as follows. In the first contribution, the effects of a 90% reduction in mobile termination rates (MTRs) are evaluated over the period between 2009 and 2017. The results show that prepaid prices, mainly used by poor consumers, and quality-adjusted postpaid prices, mainly used by higher-income consumers, declined by over 40%. However, only approximately 30% of the decline in prepaid prices and 60% of the reduction in quality-adjusted postpaid prices can be explained by lower MTR costs. On-net and off-net prepaid prices converged as MTR costs declined. This suggests that mobile network operators did not fully pass through reductions in marginal costs which indicates that operators have a degree of market power as they are able to charge mark-ups over costs. Furthermore, incumbent operators' ability to exclude rivals via on-net discounts, generating 'tariff-mediated network effects', is diminished after termination rates are regulated. These results suggest that regulators in developing countries might consider reducing mobile termination rates, not only in order to reduce retail prices directly but also to facilitate the expansion of new entrants.

In the second contribution, we evaluate the distribution of the consumer welfare effects from competition versus regulation in the mobile sector. In this contribution, six waves of a consumer survey for the period between 2009 and 2014 are used, which consists of more than 134,000 individuals. First, a discrete-choice model is estimated allowing for individual-specific price-responsiveness and preferences for network operators. Next, a demand and supply equilibrium framework is used to simulate prices and the distribution of welfare in counterfactual situations without entry and without regulation. Our results show that while a 'rising tide lifts all boats', in that all consumers benefit from entry and regulation, high-income consumers benefit more in terms of consumer surplus. At the same time, regulation and new entry result in a greater increase in mobile penetration among poor consumers than among rich consumers. This suggests that governments and regulators might consider how best to ensure that the benefits of entry and regulation are extended more to low-income consumers, such as by imposing network coverage obligations on licensees.

In the third contribution, we study substitution between fixed and mobile broadband connections in South Africa using the same survey data used in the second contribution. As is the case in many developing countries, mobile data is the most widely used means of connecting to the internet in South Africa. Nonetheless, South Africa is different because fixed-lines were rolled out almost exclusively to the White minority population during apartheid. In this contribution, we estimate a discrete-choice model where individuals may choose one or both fixed and mobile voice and data services in a model that allows them to be substitutes or complements. We find that fixed and mobile voice services are complements on average but that fixed and mobile data are substitutes. However, there is a large number of consumers who see these services as complements. In particular, having a computer makes fixed and mobile broadband access complementary. Individuals with internet access at work or school facilities as well as individuals who are employed and self-employed see fixed and mobile data as weaker substitutes. In our counterfactual simulations, we show that having a computer and access to an internet connection at work or school are more important than reducing mobile data prices by 10% in driving fixed and mobile broadband penetration. Our results suggest that policymakers and regulators could consider means of expanding access to computers and internet at workplaces and schools together with expanding access to fixed-line broadband and reducing mobile data prices.

The rest of this thesis is organised in the following way. In Section 2, the price-effects of the regulation of wholesale mobile termination rates are evaluated. In Section 3, the distributional consequences of regulating wholesale termination rates versus introducing competition are analysed. An analysis of consumer heterogeneity in the complementarity or substitutability of fixed and mobile voice and data services is presented in Section 4. Conclusions from all three contributions are then discussed in Section 5.

# 2 The effects of lower mobile termination rates in South Africa

## 2.1 Introduction

The Independent Communications Authority of South Africa (ICASA) reduced mobile termination rates ('MTRs'), the price that mobile network operators ('MNOs') charge each other for calls between networks, by 90% between 2009 and 2017. However, Armstrong (1998), Laffont et al. (1998b) and Gans and King (2001) show that lower MTRs can lead to higher retail prices. This is because subscribers want to join the larger network where on-net discounts are offered. High MTRs thus create 'tariff-mediated network effects', which intensifies competition for subscribers and results in lower retail prices. This result can also be explained in the context of 'two-sided markets', where profits from one side of the market (inbound calls) are used to subsidise the other (retail prices) (Genakos and Valletti, 2012). Genakos and Valletti (2011) find evidence that lower MTRs result in higher retail prices, in one of a series of studies on the effects of MTR reductions on prices in OECD countries.

At the same time, MNOs may use high MTRs together with on-net discounts to exclude new entrants (Laffont et al., 1998b, Calzada and Valletti, 2008 and López and Rey, 2016) or to exploit their monopoly over fixed to mobile calls, and use these profits to expand the total number of mobile subscribers (Armstrong and Wright, 2009). In South Africa, two years prior to the entry of Cell C in 2001, mobile incumbents Vodacom and MTN raised MTRs for mobile to mobile calls by more than 500%. Furthermore, there was a limited-coverage fixed-line network, close to full mobile coverage over the period analysed and prepaid connection charges were close to free, which means that the 'market-expanding' effect of high MTRs is not likely. These market characteristics are quite different to the groups of developed countries studied previously, which typically have extensive fixed line networks more likely to result in low retail prices, subsidised by high MTRs.

The effects of MTR reductions in South Africa are tested here using a unique dataset on prices collected from Research ICT Africa, Tarifica and from archive.org's 'Wayback Machine'. Hedonic regressions are used to develop an index of quality-adjusted postpaid prices, rather than the more limited 'basket of use' approach used in previous studies. Price indices for telecommunications services developed by Statistics South Africa, the central statistics office, suggest that prices have been flat in nominal terms (declining in real terms, after taking into account the effects of inflation). However, the price dataset developed here shows that prepaid and quality-adjusted postpaid prices declined by more than 40% in nominal terms. Only approximately 30% of the decline in prepaid prices and 60% of the decline in quality-adjusted postpaid prices can be explained by lower MTR costs. There is some evidence that suggests that the remainder of the price reductions is explained by increased competition. It turns out that on on-net and off-net prices converged as MTRs declined, reducing the risks to competition from 'tariff-mediated network effects'.

The results suggest that regulators should continue pursuing further reductions in MTRs, particularly where they are concerned about the possibly exclusionary effects of on-net discounts. Furthermore, regulators and statistics agencies should ensure that quality-adjusted prices are used instead of average package prices, which bias postpaid prices upwards.

The rest of the paper is structured as follows. First, a brief review of the literature is provided, followed by an overview of the telecommunications industry in South Africa. Next, the methodology is discussed, followed by a description of the data and a discussion on the results. A final section provides conclusions and policy implications.

### 2.2 Literature review

MNOs may set different MTRs for fixed to mobile ('FTM') and mobile to mobile ('MTM') calls. Armstrong and Wright (2009) show that MNOs able to discriminate between FTM and MTM MTRs will set the FTM MTR at close to monopoly levels, while the MTM MTR would be set at or below cost. The latter result is driven by the fact that high MTM MTRs together with on-net discounts mean that consumers prefer to join the larger network, which generates network effects. These 'tariff-mediated network effects' intensify competition among MNOs for subscribers (Laffont et al., 1998b and Gans and King, 2001). As a result of more intense competition, profits from high MTRs are passed back to consumers via low on-net charges and lower monthly subscription charges. Thus, MNOs prefer an MTM MTR that is low, in order to 'soften competition'. More recent research has shown that these results rely on expectations being 'responsive', such that where an operator reduces prices, consumers expect an increase in the operator's market share (Hurkens and López, 2014). Where expectations are 'passive', the network effect is subdued, and in a duopoly retail prices even rise with higher MTRs. Where competition is in linear (prepaid) prices, on-net prices are unrelated to MTRs since network effects are limited, while off-net prices rise with MTRs. Nonetheless, the 'waterbed effect' (prices rise when MTRs fall) is expected when there are three or more networks.

MNOs set monopoly MTRs for FTM calls since they do not compete with fixed line operators, and so 'tariff-mediated network externalities' are not generated (Armstrong and Wright, 2009).[1] At the same time, profits from terminating FTM calls are passed back to consumers through competition at the retail level. Where there are 'market-expanding' effects, pass-through is less than 100% and MNOs therefore strictly prefer a high FTM MTR. However, in South Africa over the period analysed (2009-2017), both MTN and Vodacom's networks were close to full-coverage, and network connection charges were close to zero (the price of a prepaid SIM card over the entire period was close to zero). Also, mobile penetration increased as MTRs fell over this period (see Figure 2). Thus, the 'market expanding' rationale does not explain the persistent use of high MTRs.

That MNOs in South Africa, where there was a limited-coverage fixed-line network, raised MTM MTRs by more than 500% between 1999 and 2001 (from R0.20 per minute to the FTM MTR of R1.09 per minute), is something of a puzzle given the 'tariff-mediated network externalities' that arise. The former CEO of Vodacom claimed that they needed to equalise the MTM and FTM MTR in order to comply with new non-discrimination requirements published by the regulator in 1999 (Knott-Craig, 2009). However, they could have chosen the lower MTM rate (R0.20) in order to comply with this obligation, if it was in their interests to soften competition for mobile subscribers (already at the time anticipated to be far greater in number than fixed line subscribers). That they did not do so means that we need to consider alternative economic reasons that might explain high MTRs.

The first and most plausible explanation is that MTN and Vodacom raised the MTR in 1999 because of the imminent entry of Cell C, a third MNO, in 2001 (Aproskie et al., 2008). Incumbents facing new entry are able to use 'tariff-mediated network externalities' to block entry, since consumers prefer the larger network where on-net discounts are present (Laffont et al., 1998b, Calzada and Valletti, 2008 and López and Rey, 2016)).

[1] The subscriber's MNO has a monopoly over inbound calls because calls to the subscriber must be terminated via the subscriber's MNO.

Nonetheless, there are other possible explanations for MTN and Vodacom choosing high MTRs. For example, where operators are unable to discriminate between on-net and off-net prices and compete in linear (prepaid) prices, profits increase by raising MTRs since each operator avoids discounting retail prices, which would generate high termination costs (Laffont et al., 1998a). While this outcome is also a possibility where on-net discounts are permitted (as is the case in South Africa), this is only where substitutability between networks is close to zero (Laffont et al., 1998b). MNOs in South Africa are highly substitutable since prepaid churn is in excess of 50% (Vodacom, 2009 - 2017), and therefore using high MTRs as a collusive device for linear prices seems unlikely.

There are other theories explaining high MTRs based on operators discriminating between heterogenous customers (Dessein, 2003, Dessein, 2004, Hahn, 2004, Jullien et al., 2013 and Hoernig et al., 2014). For example, if light users receive calls but do not make them, then operators compete vigorously for light users when MTRs are high but pass-through of revenues from high MTRs to retail prices is not 100%, and operators favour a high MTR (Jullien et al., 2013). If light users are price-sensitive, then the low prices that result have a market-expanding effect too. However, these models apply to specific market settings, including that operators are highly differentiated or that customers select their network based on the MNO chosen by friends and family. Operators in South Africa, where churn among prepaid customers is high (more than 50% for prepaid customers), are not highly differentiated. Furthermore, most consumers do not select only one network, since they have more than one active SIM card (i.e. they are connected to two or more networks at the same time): there are approximately 90m connections reported by mobile operators, and only 40m persons aged 15 and older.

The most plausible explanation for high MTRs in South Africa is therefore exclusion via 'tariff-mediated network effects'. Nonetheless, it is at least possible that MTN and Vodacom chose high MTRs in order to exploit their monopolies over FTM calls (and pass this back to consumers in the retail market) or wished to encourage unconnected users to take up their services. If this were true, then we would expect to see a 'waterbed effect' when MTRs decline. Testing for 'waterbed effects' therefore helps us test for the rationale for MTN and Vodacom choosing high MTRs together with on-net discounts.

A number of studies have assessed the impact of reduced MTRs on retail prices in developed countries. However, developed countries typically have close to full-coverage fixed line networks, and mobile operators have an incentive to set a high MTR to exploit their FTM monopoly (lower MTRs result in a 'waterbed effect'). Furthermore all of the empirical papers on MTR reductions consider cross-country data, which makes testing for exclusionary effects difficult. For example, Genakos and Valletti (2011) found that MTR reductions resulted in higher retail prices in a study of more than 20 OECD countries. The same authors more recently found that this 'waterbed effect' had disappeared over time in a study on an expanded group of 27 OECD countries, due to the diminishing role of fixed line networks (Genakos and Valletti, 2015). Kongaut and Bohlin (2014) find that MTR reductions led to decreases in retail prices in a study on 39 European countries. Veronese and Pesendorfer (2009) found no relationship between MTR reductions and retail prices in a study on 39 OECD countries. Wernick et al. (2010) find a strong relationship between reductions in MTRs and lower retail prices for services in 16 European countries. Grzybowski (2008) finds that reductions in MTRs for fixed line services were passed through to retail prices by incumbent operators in the EU between 1998 and 2002, resulting in retail prices that were 8.2% lower over the period.

Stork and Gillwald (2014) qualitatively evaluate the impact of MTR reductions in Kenya, Namibia and South Africa. They find lower retail prepaid prices in all three cases. However, their approach does not quantify the impact of lower MTRs, does not take into account non-linear (postpaid) tariffs, including changes in the quality of postpaid tariffs over time, nor does it take into account differences between on-net and off-net prices.

In the approach followed here, retail on-net and off-net retail prepaid voice prices per minute are regressed on termination costs per minute. In addition, monthly subscription charges, adjusted for quality using the hedonic method, are regressed on termination costs per minute. The hedonic regression approach holds package characteristics (such as minutes of use, gigabytes of data etc.) constant. This technique, introduced by Court (1939) and popularised by Griliches (1961), was motivated as a means of avoiding upward bias in the calculation of consumer price indices by statistics agencies. Taking changes in quality into account can result in significantly lower prices (Pakes, 2003).

Karamti and Grzybowski (2010) estimate hedonic price regressions for three mobile operators in France, and found that the introduction of a third operator in the market caused prices to decline significantly and quality to improve significantly. While the quality-adjusted price index for prepaid prices decreased significantly, quality adjusted postpaid price reductions were more muted. Schöni and Seger (2014) compare hedonic price indices for individual mobile operators in Switzerland, and find that there are indeed linear relationships between prices and product characteristics, and that the hedonic models improve on the 'basket of service' approach recommended by the OECD for price comparisons. Forenbacher et al. (2016) also estimate quality-adjusted postpaid telecommunications prices for Croatia using hedonic regressions, finding that quality-adjusted prices fell over time. Adjusting postpaid prices for quality is therefore an important step in developing an informative dataset on postpaid price trends.

The literature on the effects of MTRs is extended here in a number of ways. First, the effects of MTR reductions on on-net discounts is tested for empirically for the first time. Furthermore, the impact of lower MTRs in a developing country with a limited-coverage fixed line network, where an exclusionary rationale for high MTRs is more plausible, has not been tested for. Finally, 'quality-adjusted' prices have not been used in testing for the effects of lower MTRs.

### 2.3 Industry overview

Markets for telecommunications services in South Africa are highly concentrated. There is a fixed-line network that has partial coverage (Telkom, the former fixed-line monopolist), which supplies around 3m fixed lines out of 15m households. There are two full-coverage MNOs (MTN and Vodacom, licenced in the mid-1990s), two smaller, partial-coverage MNOs (Cell C and Telkom Mobile, which started operations in 2001 and 2009 respectively) and several mobile virtual network operators (MVNOs), the largest of which is Virgin Mobile. Telkom, the former fixed-line monopoly, owned 50% of Vodacom until 2009, after which Telkom began offering mobile services ('Telkom Mobile') directly in the fourth quarter of 2010. Cell C and Telkom Mobile currently roam on the Vodacom and MTN networks respectively outside of their coverage areas, while Virgin Mobile is an MVNO on the Cell C network. There are therefore only two full-coverage MNOs and good reasons to be concerned about high levels of concentration.

MTRs can be commercially negotiated between network operators or set by the telecommunications regulator, and may be different for fixed to mobile ('FTM') and mobile to mobile ('MTM') calls. MTRs were set by commercial negotiation initially in the mid-1990s, when MTN and Vodacom agreed on MTRs at R0.20 per minute for MTM calls and R1.09 for FTM calls. The MTM MTR was later raised by 500% to the FTM MTR in the two years leading up to Cell C's entry in 2001 to R1.09 (Knott-Craig, 2009). The converged MTR reached R1.25 per minute during peak hours in 2009, which is especially high given that cost-based MTRs on the MTN and Vodacom networks was R0.13 in 2017.

At the same time that Telkom sold its stake in Vodacom and entered the mobile services sector directly in 2009 and 2010, pressure from parliamentarians and the government (which owns in excess of 40% of Telkom) led to the reduction of MTRs by agreement between the MNOs and the government. The Independent Communications Authority of South Africa (ICASA) subsequently promulgated regulations that set maximum MTRs for calls to the incumbent (MTN and Vodacom) networks, and a higher asymmetric rate for calls to smaller networks, in 2010, according to a glide path. As a result, MTRs declined by 90% between 2009 and 2017 (see Figure 1). The main question addressed in this paper is what effect this reduction in MTRs had on retail prices in South Africa.

Despite the substantial reductions in MTRs, retail telecommunications prices have been relatively flat in nominal terms over the period 2009-2016 according to Statistics South Africa (see Figure 1). After accounting for the effects of overall inflation in South Africa, measured by the Consumer Price Index ('CPI' on Figure 1), retail prices for telephone, cellphone and internet services have fallen. In what follows, prices and termination costs are analysed in nominal terms. As will become clear from the results set out below, it appears as though Statistics South Africa has not captured improvements in postpaid package quality (improvements in package characteristics), nor reductions in prepaid prices, in the computation of telephone, cellphone and internet price indices. This has likely resulted in an upward bias in the overall consumer price index.

The market shares of incumbent operators MTN and Vodacom, measured by number of active subscribers, have declined only marginally while new entrants Cell C, Telkom Mobile and Virgin Mobile, have grown their market shares by only a small amount (see Figure 2). At the same time, mobile penetration and therefore the number of subscribers on each network has increased significantly. Mobile penetration increased from 76% in 2010 to 89% in 2014 (South African Audience Research Foundation (SAARF), 2009-2014; see Figure 2). Both prepaid and

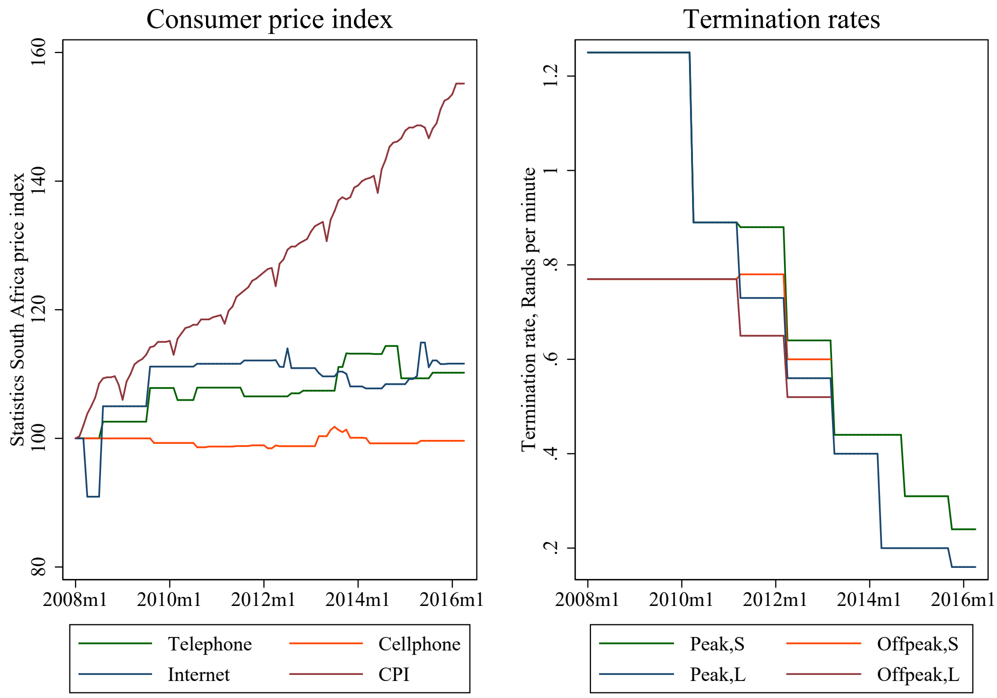



**Figure 1: Telecommunications price indices in the Statistics South Africa consumer price index (Monthly, 2008-2016)**

Sources: Consumer price index: Statistics South Africa (2016); Termination rates: Government Gazettes. Note: On the termination rates graph, 'S' and 'L' denotes small and large operator respectively.

postpaid subscribers grew in number between 2010 and 2014. However, the number of prepaid customers grew more quickly than postpaid customers. Consumers on postpaid plans increased from 8% in 2010 to 9% of all consumers, including the unconnected, in 2014, while consumers on prepaid plans grew from 68% of all consumers in 2010 to 80% in 2014. There is therefore a significant shift among consumers towards using prepaid plans.

## 2.4 Methodology

Our objective is to test for a relationship between retail prices and MTRs, which may be positively related if high MTRs are used for exclusionary purposes, or negatively related if low MTRs 'soften competition' or are used for 'market-expanding' purposes. Where high MTRs are chosen for exclusionary purposes, we would expect MTR reductions to result in lower retail prices. Where low MTRs result in a 'softening of competition' or are used for 'market expanding' purposes we would expect a 'waterbed effect' (higher retail prices).

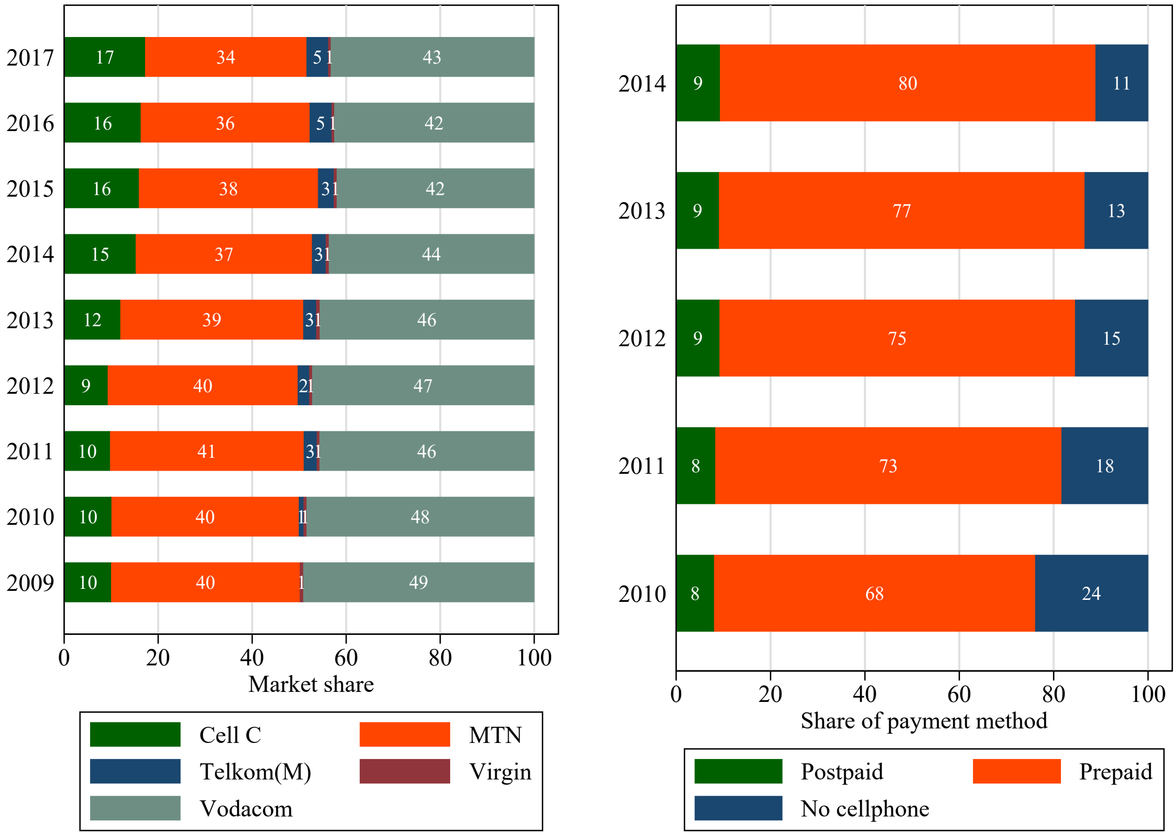



**Figure 2: Market shares (2009-2017) and payment methods (2010-2014)**

Sources: Operator market shares are calculated from the number of connections in operator annual reports and public statements. The share of prepaid, postpaid and unconnected consumers is calculated from South African Audience Research Foundation (SAARF) (2009-2014).

The quality-adjusted postpaid prices, and prepaid prices (including on-net and off-net prices), are separately regressed against the termination costs per minute faced by each operator in order to estimate the impact of reduced MTRs on retail prices. The effects of lower MTRs are identified both in variation over time and in variation between operators, since larger operators charge lower MTRs than smaller operators in South Africa, and termination costs vary by operator depending on their market share.

The relationship to be estimated between prepaid (linear) prices and termination costs is as follows:

$$L_{ijt} = \alpha + \beta MTR_{jt} + \sum_{j=1}^{5} \lambda_j M_j + \sum_{t=1}^{n} \tau_t D_t + \gamma Pk + \psi HHI_t + \mu_{ijt} \tag{1}$$

where $L_{ijt}$ corresponds to operator $j$'s linear (prepaid) off-net price, or on-net discount (off-net minus on-net price), for prepaid plan $i$ in time period $t$. Off-net prices and on-net discounts are regressed separately on the explanatory variables. Equation 1 is estimated using pooled (i.e. all prepaid packages), mean and minimum prices per operator per quarter. The key parameter of interest is $\beta$, which captures the impact of termination costs ($MTR_{jt}$) on prepaid prices. Termination costs per minute are calculated by weighting the MTRs using operator market shares.[2] Time fixed-effects ($D$) are included in order to eliminate any common time trend in prepaid prices and termination costs if, for example, prepaid prices are falling in line with telecommunications prices more generally and operator costs fall as the number of total subscribers grows over time (see Figure 2). If not controlled for, these common time trends may result in 'spurious correlation'. A further dummy variable for 'peak hour' ($Pk$ in Equation 1) prepaid prices is included as most operators charge different peak and off-peak prices. Fixed-effects for each operator ($j$) are captured by the coefficients $\lambda$ on operator dummy variables ($M$), and $\psi$ captures the effects of changes in market concentration in each time period ($t$), measured by the Herfindahl-Hirschman Index ($HHI$). Residuals are captured by the error term $\mu$.

In order to estimate the effects of lower MTRs on postpaid prices (Equation 3), quality-adjusted postpaid prices are developed for each mobile operator, using the hedonic pricing approach. The linear hedonic model to be estimated is as follows:

$$P_{ijt} = \alpha + \sum_{i=1}^{m} \beta_i X_{ijt} + \sum_{j=1}^{5} \lambda_j M_j + \tau D_{t+1} + \sum_{j=1}^{5} \gamma_j M_j D_{t+1} + \epsilon_{ijt} \tag{2}$$

where $P_{ijt}$ are prices ($P$) for package $i$ offered by operator $j$ in time $t$, $X_{ijt}$ are product characteristics for package $i$ offered by operator $j$ in time $t$. $\beta_{it}$ are sometimes referred to as 'shadow prices' for characteristics ($X_{ijt}$), which may not be consistent over time (Pakes, 2003). In order to calculate the quality-adjusted prices for each operator, data for adjacent years are pooled. This constrains coefficients for product characteristics ($\beta$) to be consistent over the two year period, which is the least pernicious constraint (Triplett, 2004). $M_j$ are operator dummy variables and $\lambda_j$ are the brand premia or discounts consumers are willing to pay. $\tau$, the coefficients on the second-year dummy variables ($D_{t+1}$), are quality-adjusted prices in each year. The coefficients $\gamma$

[2] Termination costs per minute are calculated as follows: $TC_{jt} = \sum_{k=1}^{k} (M_{kt} \times TR_{kt})$, where $j \neq k$ and where $TC_{jt}$ is operator $j$'s termination costs ($TC$) in time period $t$, $M_{kt}$ is operator $k$'s market share in time $t$, and $TR_{kt}$ is operator $k$'s termination rate in time $t$.

are quality-adjusted price changes undertaken by each operator $j$ in time $t$, measured by the interaction of operator dummy variables ($M_j$) and the dummy variable on the second year ($D_{t+1}$) for each pair of adjacent years. Errors are captured in the term $\epsilon_{ijt}$. The year ($\tau_t$), operator ($\lambda_j$) and operator-year interaction term coefficients ($\gamma$), are used to develop the hedonic index.

The relationship between quality-adjusted postpaid prices and termination costs is estimated as follows:

$$Q_{jt} = \alpha + \beta MTR_{jt} + \sum_{j=1}^{5} \lambda_j M_j + \varepsilon_{jt} \tag{3}$$

where $Q_{jt}$ are quality-adjusted postpaid prices ($Q$) offered by operator $j$ in time period $t$ (estimated in Equation 2) and $\beta$ captures the effects of MTR costs per minute ($MTR_{jt}$). $\lambda_j$ captures operator ($M_j$) fixed-effects. The HHI, used to measure changes in concentration in Equation 1, is dropped in Equation 3 because the HHI is calculated using the total number of subscribers (all operators do not report prepaid and postpaid subscribers separately), which more accurately reflects changes in concentration in respect of prepaid customers since most consumers use prepaid packages. In any event, there are very low rates of postpaid consumer churn (less than 10% in the case of Vodacom (2009 - 2017)), which suggests that annual changes in postpaid concentration are likely to be minimal. Termination costs per minute are calculated by weighting the MTRs paid by the operator by market shares, in the same way as they are calculated for the prepaid estimation. The error term $\varepsilon_{jt}$ captures any remaining variation. Note that there is no time trend in the postpaid estimation, since this is captured in the first stage hedonic regression.

### 2.5 Data

There are $1,314$ quarterly prepaid price observations in the dataset (including peak and off-peak), collected from from Research ICT Africa, from operator websites and from archive.org's 'Wayback Machine'.[3] There are two observations for each prepaid price plan, one for peak hours and one for off-peak hours. Each prepaid price plan also has different prices for on-net and off-net calls. Descriptive statistics are available on Table 1.

Retail prepaid prices declined significantly over the period 2009-2017, as did termination costs (see Figure 3). Prepaid prices declined in 2013 to as low as R0.50 per minute off-net and

[3] Prepaid and postpaid prices for 2017 were collected in September 2017. The prepaid price (collected in Q3 2017) was applied to all four quarters. Prepaid prices are not adjusted regularly and therefore this approach is unlikely to affect the results.

**Table 1: Descriptive statistics: postpaid packages, prepaid prices and MTRs**

| | N | Mean | SD | Min | Max |
|---|---|---|---|---|---|
| **Prepaid price variables** | | | | | |
| Off-net (Rands per minute) | 1314 | 1.76 | 0.74 | 0.50 | 3.50 |
| On-net (Rands per minute) | 1314 | 1.60 | 0.67 | 0.29 | 3.20 |
| Peak (% of prepaid obs) | 1314 | 0.50 | 0.50 | 0.00 | 1.00 |
| **Mobile termination rate (MTR) variables** | | | | | |
| MTRs (Rands per minute) | 1314 | 0.14 | 0.13 | 0.00 | 0.61 |
| Market shares | 1314 | 0.30 | 0.17 | 0.01 | 0.49 |
| MTR costs (Rands per minute) | 1314 | 0.32 | 0.22 | 0.09 | 1.24 |
| **Postpaid variables** | | | | | |
| Tariff (Rands per month) | 1459 | 398.3 | 390.8 | 9 | 2965 |
| Minutes included (all-net) | 1459 | 106.9 | 244.8 | 0 | 3000 |
| Minutes included (on-net) | 1459 | 23.3 | 126.9 | 0 | 1000 |
| SMS included | 1459 | 99.0 | 229.6 | 0 | 1600 |
| Data (GB) included | 1459 | 0.88 | 1.98 | 0 | 10 |
| Credit value per month | 1459 | 136.1 | 259.7 | 0 | 1600 |
| Unlimited package | 1459 | 0.028 | 0.17 | 0 | 1 |
| Device included | 1459 | 0.29 | 0.46 | 0 | 1 |

R0.30 per minute on-net but recovered in later years as a temporary price war came to an end (see Figure 3). There are minor exceptions to this general trend, such as where Virgin Mobile raised its prepaid price from R1.99 to R2.60 in the second quarter of 2011, and eliminated its '1 2 Free' package towards the end of 2014, thereby resulting in the lowest price package increasing from R0.99 to R1.29 in Q2 2015. Furthermore, Telkom Mobile increased its prices for its 'Prepaid Voice' product in late 2012 and early 2013, while offering discounts based on recharge value (the higher the value, the deeper the discount). 'Bonus offers' of this sort, as well as dynamic discounts for on-net calls based on time of day and location, offered by MTN (Zone) and Vodacom (4Less), are not used here. This is because data on these discounts over time are not readily available, and in any event they are often offered as promotions and subsequently withdrawn, which makes measurement difficult. This means that on-net discounts, particularly by MTN and Vodacom, are likely to be understated in the coefficients estimated here. At the same time, the declining price trends shown on Figure 3 are in line with declining average retail voice prices reported by MTN and Vodacom in annual reports, which take into account all discounts (Hawthorne, 2016). This means that the relationships between prepaid prices and MTRs estimated here are unlikely to be biased significantly.

Off-net prepaid prices are typically more expensive than on-net prices, which suggests that

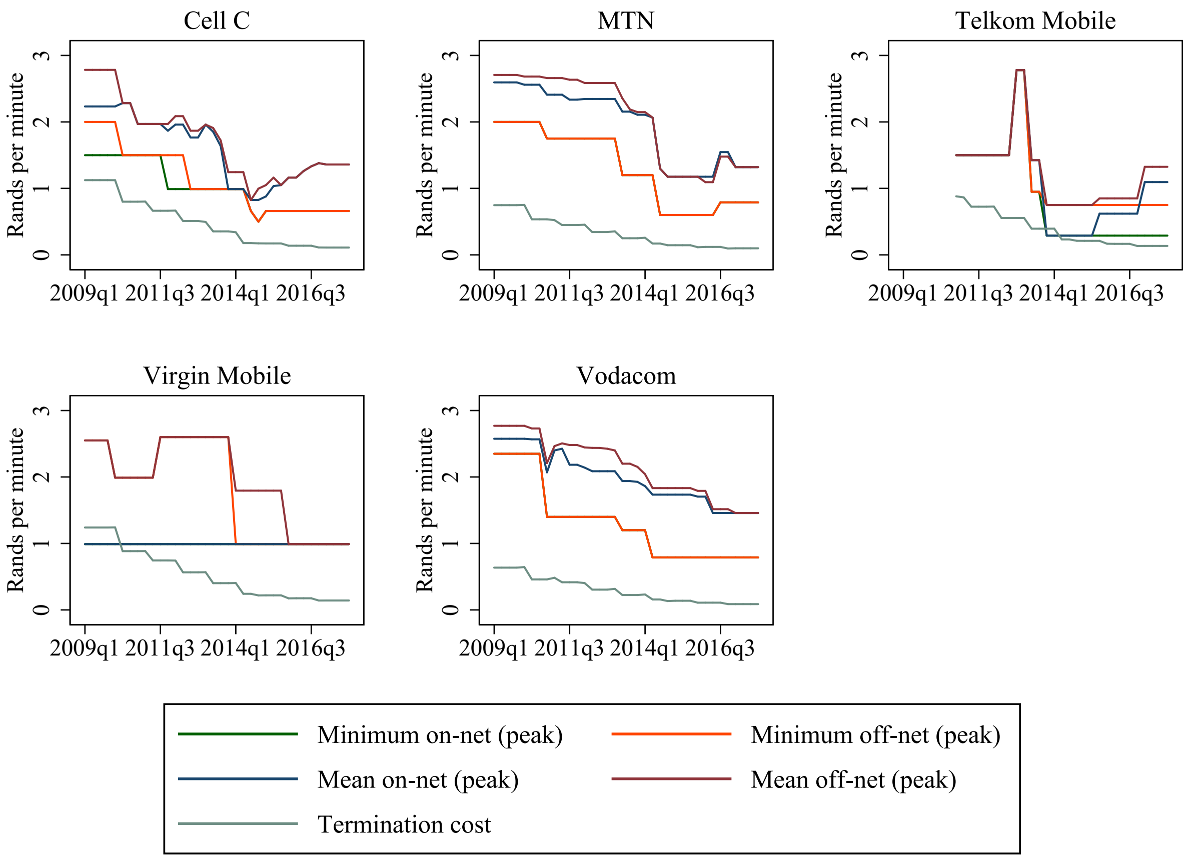



**Figure 3: Minimum and mean peak-hour quarterly prepaid voice prices (Rands per minute, 2009-2017)**

operators employ on-net discounts to a significant degree (see Figure 3). Nonetheless, on-net and off-net prices have converged to a significant extent at each operator, in line with the reductions in MTRs (see Figure 3).

Average postpaid package prices (see Figure 4) remained stable between 2009 and 2017, at approximately R400 per month, which is roughly in line with the Statistics South Africa price index for cellphone services (see Figure 1). This is surprising given the changes in the market over the period, and indeed motivates the use of hedonic price regressions to adjust for changes in quality.

There are 1,459 annual postpaid subscription observations in the dataset (see Table 1). Postpaid prices were collected from archive.org's 'wayback machine' and from Tarifica, an organisation that collates mobile prices, and from other industry analysts, including websites such as MyBroadband.co.za, publications such as the 'broadband bible', and from operator websites.

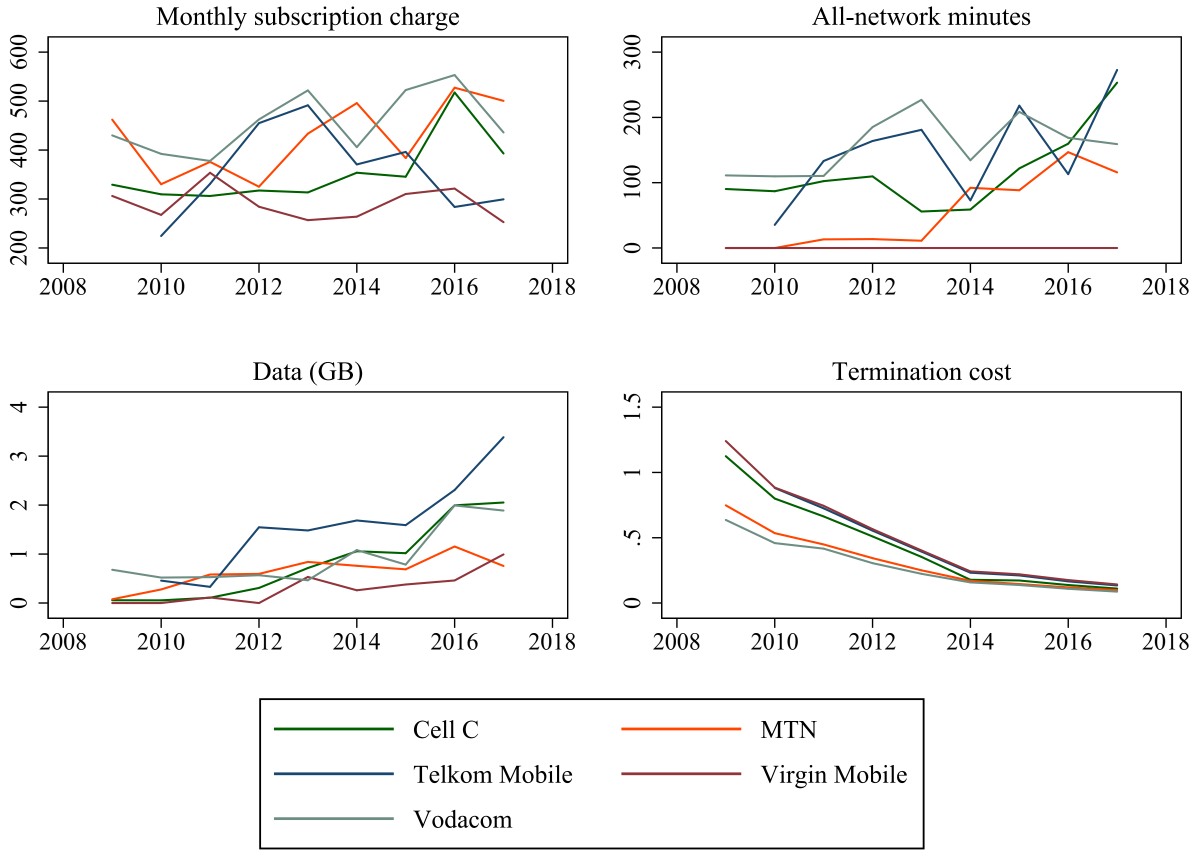



**Figure 4: Postpaid monthly subscription charges, included minutes, included data and termination costs (2009-2017)**

The value included in packages, such as the number of included voice calling minutes and gigabytes of data ('GB'), increased significantly over the period (see Figure 4). There are data-only and voice-only packages, and therefore the minima for voice and data packages are zero. A small number of data packages above 10GB was dropped from the dataset, since these are likely to belong to a different product set competing mainly with fixed-line broadband (fixed-replacement products).

Unlimited voice and data packages were introduced in 2013 and have grown as a proportion of all packages offered, accounting in later periods for approximately 3% of packages. Unlimited voice packages tend to have a 'fair usage policy' ('FUP'), typically of 5,000 minutes.[4] While 'unlimited' data packages also exist, these typically have a fairly low FUP, which varied over the

[4]The FUP for voice minutes was not recorded under the 'minutes' variable since it far exceeds the maximum possible usable minutes.

years between approximately 3GB and approximately 10GB.[5]

Other characteristics used in the hedonic regressions, including credit value, devices included and packages available on contract vary from year to year and between operators somewhat but do not increase significantly over time. Only one device (such as a smartphone or feature phone) was selected per postpaid package in most cases. There are therefore typically two observations per postpaid package: one with a device, and one without. This is unlikely to skew results significantly since often there was only one device available per package at the point in time for which data was collected (typically July in a given year) and in some instances a package variant was available with a generic 'device' option. Where possible, the same device was chosen across operators and across packages. Devices are only offered on contract (typically over 24 months), and therefore the 'device' and 'contract' variables are collected in similar proportions.

MTRs declined significantly between 2009 and 2017 (see Figure 1), as did termination costs (see Figure 4). MTRs are published in government gazettes, and operator market shares were computed using operator annual reports and other publicly available information on the number of subscribers per operator. While MTN, Vodacom and Telkom Mobile announce their subscriber numbers in annual reports, Virgin Mobile and Cell C do not and report their subscriber numbers only periodically in the press.[6] Small operators have higher termination costs per minute than large operators, though these costs have declined significantly in recent years and have converged to a significant extent with those of large operators (see Figure 4 and Figure 3). There are two categories of MTRs: one for large operators (incumbents) and one for small operators (new entrants). Prior to March 2013, there were different MTRs for peak and off-peak time periods (see Figure 1). Peak and off-peak MTRs converged in March 2013 as part of ICASA's regulatory intervention. Because prepaid prices have peak and off-peak rates, they were regressed against peak and off-peak termination costs. However, only peak MTR costs per minute were regressed against quality-adjusted postpaid prices since the latter do not differentiate between peak and off-peak hours to the same extent, and because peak hour calls likely account for the bulk of postpaid customer calls (and therefore matter the most for costs). Further details on MTRs,

[5]The maximum data allowance under unlimited was recorded under the data allowance variable as far as possible.

[6]Virgin in particular reported its subscribers only once, and therefore we have used the same number (0.5m) over the period analysed. Publicly available information, including the AMPS survey (South African Audience Research Foundation (SAARF), 2009-2014) shown on Figure 2, suggests that Virgin Mobile has not grown significantly in South Africa.

operator market shares and MTR costs can be found in Table 1.

## 2.6 Results

Termination costs have a positive relationship with off-net prepaid voice prices and on-net discounts (see Table 2). A R1 reduction in termination costs results in a reduction in linear off-net prices of between R0.50 and R0.68 per minute, and in a reduction in the difference between off-net and on-net prices of between R0.30 and R0.53 per minute. The time fixed-effects are in some cases substantial and negatively related to price (prices declined over time). There is also evidence that changes in concentration are also positively related to off-net prepaid prices in the termination cost model (i.e. as markets become less concentrated, prices fall; see Table 2). An increased in 1,000 HHI points results in a reduction of almost R1 in off-net prepaid prices, though we could not reject the null hypothesis that there is no relationship between HHI and on-net discounts at even the 10% level of significance.

Overall over the period 2009-2017, average on-net prepaid prices declined by 36%, while average off-net prepaid prices declined by 43%. The minimum on-net price offered by each operator declined by 38% on average over all five operators, and the minimum off-net price declined by 53%. The difference between average on-net and off-net prices was almost eliminated over the period, though only 45% of the difference between minimum off-net and on-net charges was eliminated.

However, the reduction in prepaid prices and on-net discounts attributable to lower MTR costs was only 12% in respect of mean off-net prices (28% of the overall decline of 43%) and 18% in respect of minimum off-net prices (34% of the overall reduction of 53%). The remainder of the decline in prices is due to reductions in concentration and time trends. Thus, reducing MTRs plays an important role in reducing off-net prepaid prices, though this effect is somewhat muted once time trends and reductions in concentration are accounted for.

On-net discounts, in respect of mean prices offered by operators, declined by R0.28 per minute as a result of lower MTR costs (almost eliminating the difference between on-net and off-net prices in 2009, which was R0.31 per minute). In respect of minimum on-net and off-net prices offered by each operator, on-net discounts declined by R0.25 as a result of lower MTR costs, thus eliminating close to half the on-net / off-net differential in 2009 (0.55 on average

**Table 2: Estimation results - prepaid, termination costs**

| | Pooled prices | | Mean prices | | Minimum prices | |
|---|---|---|---|---|---|---|
| | **Off-net price** | **On-net discount** | **Off-net price** | **On-net discount** | **Off-net price** | **On-net discount** |
| MTR cost | 0.57** | 0.30*** | 0.50** | 0.49** | 0.68*** | 0.53** |
| | (0.2) | (0.09) | (0.2) | (0.2) | (0.1) | (0.2) |
| HHI ('000) | 0.78*** | 0.13 | 0.91*** | 0.23 | 0.92*** | 0.17 |
| | (0.2) | (0.08) | (0.2) | (0.2) | (0.2) | (0.2) |
| MTN | 0.45*** | 0.051* | 0.48*** | 0.067 | 0.31*** | -0.080 |
| | (0.05) | (0.02) | (0.05) | (0.05) | (0.05) | (0.05) |
| Telkom(M) | -0.22** | 0.15*** | -0.23*** | 0.13** | 0.13** | 0.15** |
| | (0.07) | (0.03) | (0.05) | (0.05) | (0.05) | (0.05) |
| Virgin | 0.12 | 0.54*** | 0.13* | 0.57*** | 0.51*** | 0.57*** |
| | (0.07) | (0.03) | (0.05) | (0.05) | (0.04) | (0.05) |
| Vodacom | 0.47*** | 0.11*** | 0.50*** | 0.12* | 0.24*** | 0.087 |
| | (0.05) | (0.02) | (0.06) | (0.05) | (0.05) | (0.05) |
| 2010 | -0.050 | -0.036 | -0.12+ | -0.12+ | -0.090 | -0.092 |
| | (0.08) | (0.04) | (0.07) | (0.06) | (0.06) | (0.07) |
| 2011 | 0.030 | -0.028 | -0.014 | -0.11+ | -0.015 | -0.066 |
| | (0.07) | (0.03) | (0.06) | (0.06) | (0.05) | (0.06) |
| 2012 | -0.016 | 0.058+ | -0.042 | -0.036 | -0.029 | -0.017 |
| | (0.07) | (0.03) | (0.07) | (0.06) | (0.06) | (0.07) |
| 2013 | 0.036 | 0.061* | 0.046 | 0.061 | 0.014 | 0.10+ |
| | (0.06) | (0.03) | (0.06) | (0.06) | (0.05) | (0.06) |
| 2014 | -0.12+ | 0.032 | -0.18** | 0.10+ | -0.18*** | 0.064 |
| | (0.07) | (0.03) | (0.06) | (0.06) | (0.05) | (0.06) |
| 2015 | -0.20** | 0.020 | -0.19** | 0.076 | -0.18** | -0.0017 |
| | (0.06) | (0.03) | (0.06) | (0.06) | (0.05) | (0.06) |
| 2016 | -0.079 | -0.012 | -0.12+ | -0.016 | -0.049 | -0.014 |
| | (0.07) | (0.03) | (0.07) | (0.06) | (0.06) | (0.06) |
| Peak | 0.31*** | 0.038* | 0.30*** | 0.083** | 0.16*** | 0.042 |
| | (0.03) | (0.02) | (0.03) | (0.03) | (0.03) | (0.03) |
| Constant | -1.69** | -0.55+ | -2.14*** | -0.99+ | -2.70*** | -0.89 |
| | (0.6) | (0.3) | (0.6) | (0.5) | (0.5) | (0.6) |
| R-squared | 0.38 | 0.29 | 0.75 | 0.53 | 0.79 | 0.55 |
| Number of obs | 1314 | 1314 | 346 | 346 | 346 | 346 |

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

Note: Standard errors in parentheses. 'Pooled' means all prepaid prices in the dataset, 'minimum' means the minimum available price offered by an operator in each quarter, and 'mean' means the average price offered by each operator in each quarter.

across the operators). This which means that any 'tariff-mediated network effects' generated by on-net and off-net price differences were more muted as MTRs declined.

Incumbent operators MTN and Vodacom charge higher prepaid prices than Cell C, Virgin Mobile and Telkom Mobile do. This suggests that MTN and Vodacom may have market power, though there may be other explanations. For example, they may be more attractive to customers or have higher costs due, for example, to greater coverage, better customer service, etc.

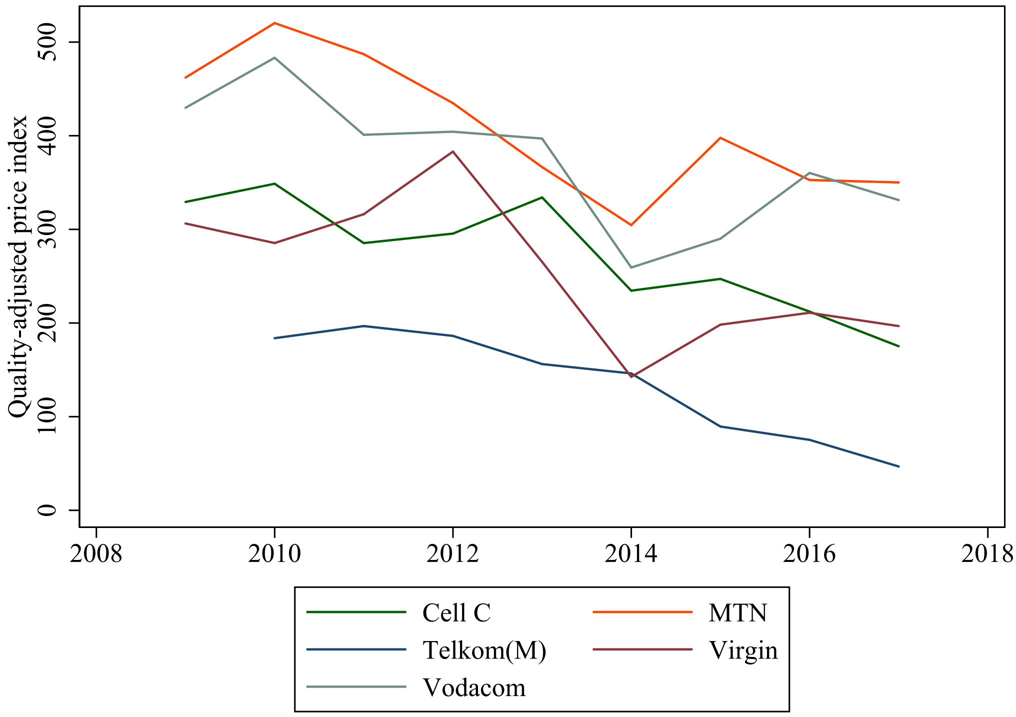



**Figure 5: Postpaid quality-adjusted price index per operator, 2009-2017**

Furthermore, at least Vodacom (and to some extent MTN) offers deeper on-net discounts than Cell C does (the difference between on-net and off-net prices on the Vodacom network is more than R0.10 higher on the Vodacom network than on the Cell C network; see Table 2). Note that MTN and Vodacom's prepaid prices exclude on-net dynamic discounts of up to 100%. This means that the co-efficients on the MTN and Vodacom dummies in the on-net discount models may be biased downwards (i.e. they may in fact offer even deeper on-net discounts than Cell C does).

The first stage hedonic regressions on postpaid prices shows that quality-adjusted postpaid prices declined among most operators, and on average by 40%, over the period between 2009 and 2017 (see Figure 5). The 'implicit price' of a voice call declined from approximately R1.50 per minute in 2009/2010 to R0.60 per minute in 2016/2017. The price for data was approximately R200 per gigabyte (GB) in 2009/2010, and this declined to approximately R50/GB in 2016/2017. The price for adding a device increased over the period, from around R32 in 2009/2010 to almost R250 in 2016/2017. This reflects declining handset subsidies over the period (see, for example, TechCentral.co.za, 2010). An unlimited plan typically added more than R1,500 to monthly bills in 2012/2013, though this has declined significantly to less than R700 in 2016/2017. Taking out a 12 or 24 month contract reduces the average price of packages in some periods, and in some cases significantly (by R70 or more per month).

The postpaid results show how important it is to adjust for quality (product characteristics). Without adjusting for quality, there is either no or a negative relationship between package prices and termination costs (see Table 4). After adjusting for quality, the results show that postpaid prices and termination costs are positively related. We can reject the null hypothesis that there is no relationship between quality-adjusted prices and termination costs at even the 0.1% level (see Table 4). A R1 reduction in termination costs per minute reduces average quality-adjusted postpaid package prices by R167. The reduction in MTRs, which resulted in a R0.58 reduction in termination costs per minute, therefore reduced postpaid prices on average by R97 (25% of the average price of almost R382 in 2009).

Incumbent operators MTN and Vodacom charge higher postpaid package prices than newer entrants Cell C, Virgin Mobile and Telkom Mobile. As discussed above, while these results are consistent with MTN and Vodacom having market power there may be other explanations, including that MTN and Vodacom are more desirable in the eyes of consumers or have higher costs due to having greater coverage and better customer service. Nonetheless, MTN and Vodacom certainly have persistently high market shares, accounting for more than 75% of the market in terms of numbers of subscribers (see Figure 2) and even more, measured by revenue. These persistently high market shares are consistent with market power.

The lack of competition reflected in these results is confirmed in concerns raised in policy documents including the ICT White Paper, government's proposed policy for the ICT sector in South Africa (Government of South Africa, 2016), and by independent research houses including Research ICT Africa (2016) which show that prices for telecommunications services in South Africa are significantly more expensive than in other African countries.

These results also suggest that both prepaid and quality-adjusted postpaid prices declined substantially over the period 2009-2017, contrary to the price indices developed by Statistics South Africa for telecommunications services (see Figure 1).

**Table 3: Estimation results - hedonic regressions (adjacent years, 2009-2017)**

| | **09/10** | **10/11** | **11/12** | **12/13** | **13/14** | **14/15** | **15/16** | **16/17** |
|---|---|---|---|---|---|---|---|---|
| Mins(a) | 1.5*** | 1.5*** | 1.4*** | 1.4*** | 1.3*** | 0.9*** | 0.9*** | 0.6*** |
| | (0.02) | (0.03) | (0.04) | (0.04) | (0.05) | (0.05) | (0.04) | (0.04) |
| Mins(o) | 0.4*** | 0.4*** | 0.4*** | 0.3+ | -0.1 | 0.3** | 0.3*** | 0.2** |
| | (0.1) | (0.04) | (0.07) | (0.2) | (0.4) | (0.09) | (0.07) | (0.08) |
| GB | 197*** | 174*** | 106*** | 86*** | 63*** | 36*** | 52*** | 56*** |
| | (3.7) | (3.7) | (4.6) | (5.2) | (6.3) | (6.4) | (5.3) | (4.9) |
| Credit | 0.9*** | 0.9*** | 0.9*** | 0.9*** | 0.9*** | 0.7*** | 0.8*** | 0.7*** |
| | (0.02) | (0.02) | (0.03) | (0.04) | (0.04) | (0.05) | (0.04) | (0.04) |
| Dev | 32.3* | 38.9** | 82.1*** | 89.1** | 178*** | 199*** | 204*** | 244*** |
| | (13.5) | (13.6) | (24.0) | (29.2) | (30.2) | (27.1) | (25.0) | (31.5) |
| Unlim | | | | 1514*** | 1337.3*** | 1090*** | 876*** | 667*** |
| | | | | (89.6) | (50.5) | (47.9) | (55.0) | (60.3) |
| Contr | -10.1 | -44.9** | -77.6** | 5.3 | 7.9 | -32.8 | -17.4 | -69.5* |
| | (13.2) | (14.3) | (23.7) | (24.9) | (28.9) | (28.1) | (24.9) | (27.7) |
| MTN | 30.8+ | 47.4* | 99.9** | 44.4 | -5.6 | 92.6+ | 89.4* | 93.6* |
| | (17.1) | (21.1) | (31.9) | (39.1) | (45.2) | (47.5) | (38.7) | (45.8) |
| Telk | -56.2* | -26.9 | 40.8 | -29.3 | -34.4 | 53.1 | -119.5** | -0.0 |
| | (25.6) | (27.9) | (40.5) | (42.2) | (48.9) | (50.6) | (44.6) | (59.0) |
| Virg | -20.4 | -20.6 | 69.1+ | -3.9 | -171.5** | -98.3 | -130.8** | -124.9* |
| | (22.3) | (23.9) | (41.6) | (46.3) | (58.3) | (60.2) | (43.5) | (61.1) |
| Voda | 43.6** | 45.7* | 71.3* | 87.6* | 47.3 | 62.9 | 60.4 | 197.6*** |
| | (15.6) | (17.8) | (27.6) | (35.2) | (43.3) | (44.4) | (38.6) | (46.6) |
| $y_{t+1}$ | 23.0 | -60*** | 12.4 | 50.2 | -128.3** | 20.9 | -55.2 | -84.4 |
| | (15.5) | (17.8) | (31.6) | (36.1) | (41.3) | (41.4) | (40.2) | (52.7) |
| MTN × | -11.0 | 27.7 | -74.4 | -44.9 | 116.9+ | -13.5 | 40.4 | 71.8 |
| $y_{t+1}$ | (23.8) | (27.4) | (45.3) | (53.3) | (59.8) | (63.5) | (56.5) | (66.6) |
| Virg × | -19.2 | 110*** | -31.7 | -77.7 | 146.2+ | -17.4 | 64.5 | 122.8 |
| $y_{t+1}$ | (26.1) | (30.4) | (52.4) | (61.8) | (75.7) | (74.4) | (64.2) | (82.4) |
| Voda × | -22.9 | 2.0 | -26.4 | -53.6 | 15.6 | 6.5 | 183.5** | -89.2 |
| $y_{t+1}$ | (21.0) | (23.9) | (40.0) | (47.5) | (58.3) | (58.9) | (57.5) | (68.8) |
| Telk × | | 53.8 | -79.9 | -24.3 | 106.1+ | -192.9** | 162.3* | -217.7* |
| $y_{t+1}$ | | (33.2) | (50.5) | (55.3) | (63.2) | (67.9) | (69.7) | (87.3) |
| Const | 19.0+ | 54.2*** | 7.5 | -28.2 | 52.7 | 56.1 | 38.7 | 99.8* |
| | (11.5) | (13.9) | (22.7) | (30.3) | (38.3) | (39.8) | (29.9) | (41.3) |
| $R^2$ | 0.97 | 0.96 | 0.88 | 0.87 | 0.84 | 0.77 | 0.81 | 0.76 |
| N | 239 | 291 | 323 | 331 | 313 | 349 | 391 | 385 |

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

Notes: Standard errors in parentheses. 'Mins(a)' refers to all-network minutes, 'Mins(o)' refers to on-net minutes, 'GB' refers to Gigabytes of data, 'Credit' refers to 'Credit value', 'Dev' means included device, 'Contr' means contract and 'Unlim' means unlimited.

## 2.7 Conclusion

Prepaid prices and quality-adjusted prices declined by more than 40% over the period between 2009 and 2017 in South Africa. Over the same period, MTRs were reduced by 90%. However, only a relatively small proportion of the reduction in prepaid prices (around 30%) and the reduction in quality-adjusted postpaid prices (60%) can be accounted for by changes in MTR

**Table 4: Estimation results - quality adjusted price index and termination rates**

| | **Mean prices** | **Quality adjusted prices** |
|---|---|---|
| MTR cost per minute | -64.4+ | 166.5*** |
| | (36.0) | (25.6) |
| MTN | 63.6+ | 156.9*** |
| | (31.5) | (22.4) |
| Telkom(M) | 0.08 | -132.2*** |
| | (32.1) | (22.9) |
| Virgin | -59.1+ | -28.0 |
| | (31.2) | (22.2) |
| Vodacom | 90.9** | 127.4*** |
| | (31.7) | (22.6) |
| Constant | 383.0*** | 198.6*** |
| | (27.3) | (19.5) |
| R-squared | 0.50 | 0.85 |
| Number of obs | 44.00 | 44.00 |

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

Standard errors in parentheses.

costs. Thus, the effects of lower MTR costs were not fully passed through to consumers.

Statistics South Africa's findings that prices remained flat or even increased do not appear to take into account improvements in postpaid product characteristics and lower prepaid prices, which suggests that greater emphasis be placed on quality changes and on prepaid prices.

The most striking result is the reduction by approximately 50% or more of the difference between off-net and on-net prices, the 'on-net discount'. This means that lower MTRs has reduced the risks arising from 'tariff-mediated network externalities', which can result in exclusion. While the market shares of Cell C and Telkom Mobile (new entrants) expanded between 2009 and 2017, MTN and Vodacom (incumbents) continue to dominate more than 75% of the market (measured by number of subscribers; their share is higher measured by revenue).

The first policy implication of these results is that regulators concerned about the expansion of new entrants and competition in retail tariffs should implement MTR reductions. This is especially the case in developing countries, where fixed line networks are more limited and therefore where the choice of high MTRs is likely to be more worrisome in the presence of new entry, due to their exclusionary rationale. In South Africa, even further MTR reductions are needed given the limited expansion of new entrants and the success in previous reductions resulting in lower retail prices. A 'bill and keep' (zero termination rate) regime, implemented in the USA, Canada and Hong Kong, should be considered. Further policy interventions might be necessary to facilitate new entry, including by means of providing open access to incumbent infrastructure.

Finally, the results suggest that incumbent operators MTN and Vodacom are able to charge significantly higher prepaid and postpaid prices, while offering deeper discounts for prepaid on-net calls. This means that these firms may command some degree of market power, though this needs further investigation, including by obtaining prepaid prices after dynamic on-net discounts are applied. The competition authorities and the telecommunications sector regulator, ICASA, should be cautious about any consolidation in the sector (both Vodacom and MTN have proposed acquiring other operators and sharing spectrum), and should review market power and anti-competitive conduct in the sector.

# 3 Benefits of regulation vs. competition where inequality is high: The case of mobile telephony in South Africa

## 3.1 Introduction

South Africa is the most unequal country in the world, with a Gini coefficient of 0.63 in 2015 according to World Bank statistics. This is a consequence of apartheid-era racial discrimination policies (Leibbrandt et al., 2010). The top 10% of income earners earn thirty times more than the bottom 10%. As a result of these high levels of inequality, policymakers are under pressure to find means of reducing inequality. One such policy lever is reducing the prices of consumer services through greater competition and the regulation of firms with market power.

The mobile telecommunications sector is a prime example of an industry in which the number of competitors, and thus to some extent competition, is under state control. In partcular, the State assigns radio frequency spectrum licenses.[7] Despite competition between four network operators in South Africa, the prices of mobile services are high compared to other African and developing economies (Calandro and Chair, 2016).[8] Moreover, the regulation of termination rates, which are the prices mobile operators charge one another for inbound calls to their networks, has proved to be an effective way of reducing retail prices (see, for example, Genakos and Valletti, 2015). Recently, mobile termination rates (MTRs) have been reduced in many African countries, including in Botswana, Ghana, Kenya, Mozambique, Nigeria, South Africa, Tanzania and Zambia (Mothobi, 2017).

Competition policy and sector-specific regulation of industries such as telecommunications may help to reduce income inequality. This is because mobile telecommunications services account for up to 5% of the bottom income quartile's expenditure in South Africa, for example (see Figure 6).[9] But there are limits to the impact of competition and regulation. For example, mobile operators enter the most attractive local markets first, which are in general urban areas

[7] Typically, regulators make radio frequency spectrum available to licensees, via auctions or beauty contests, and therefore establish the market structure for the sector.

[8] This is reflected in recent political debates in South Africa which led to market inquiries into the cost of data services, launched by the South African Competition Commission in 2017 and the Independent Communications Authority of South Africa in 2018.

[9] Based on authors' computations using the National Income Dynamics Survey (NIDS), which is a nationwide survey of South African individuals and households collected by the Southern Africa Labour and Development Research Unit (SALDRU) at the University of Cape Town (UCT) in four waves: 2008, 2010/2011, 2012 and 2014/2015 (Southern Africa Labour and Development Research Unit, 2008-2016).

with higher average income levels. At the same time, since spectrum licences typically impose coverage obligations on firms, competition should eventually also spread to rural and other areas with lower income levels. These coverage obligations should guarantee that the majority of the population benefits from competition between mobile networks, but the reality may be different. Furthermore, regulators in general do not control how operators set their prices with respect to different market segments. In countries with a relatively small share of wealthy consumers and large numbers of poor consumers, firms may not be willing to lower prices enough to attract less profitable consumers.

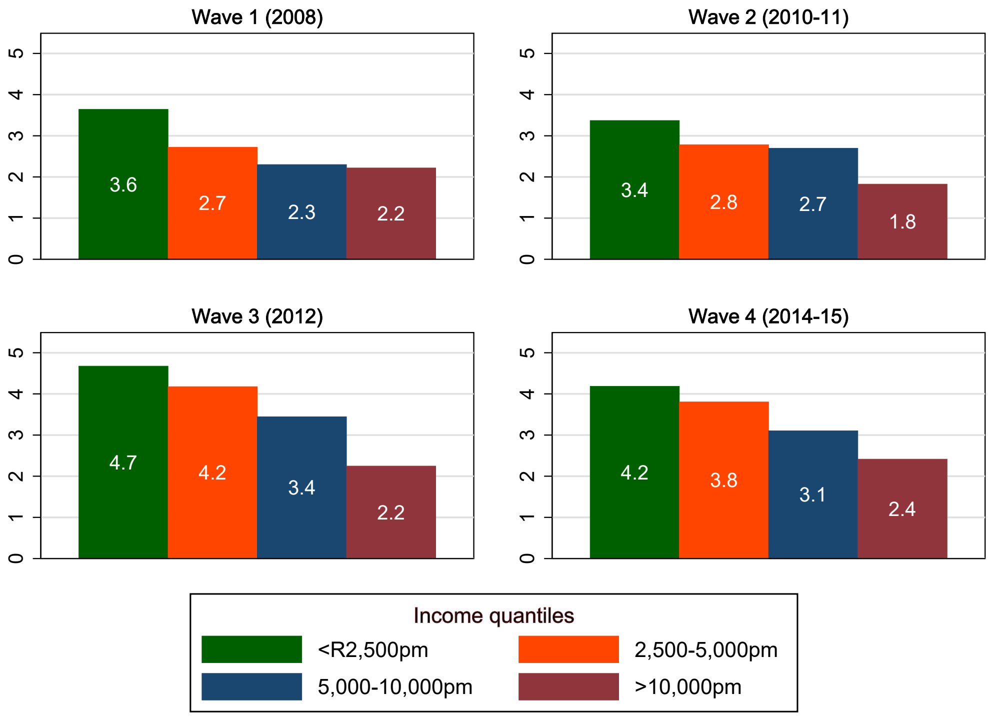



**Figure 6: Share of spend on mobile by income segments (NIDS, 2008-2015)**

Source: NIDS survey waves 2008-2015. Net income levels per month are shown on the graph.

In this paper, we use six waves of a South African survey of about 134,000 individuals collected between 2009 and 2014 to estimate the distribution of benefits across different segments of society resulting from the entry of new market players and the regulation of mobile termination rates.[10] South African society is multi-racial, multi-lingual and highly segmented with respect to

[10]We use data from the All Media Product Survey (AMPS) survey produced by the South African Audience Research Foundation (SAARF).

income, which results in differences in the affordability of mobile telecommunications services. We estimate a discrete-choice model allowing for individual-specific price-responsiveness and preferences for network operators. Overall, we find that the price sensitivity of subscriptions to mobile networks is impacted by income directly and by factors which indirectly determine individual wealth and social group, such as race and language. We use the estimates of demand parameters and individual price-responsiveness to conduct counterfactual simulations. First, we simulate market outcomes in the absence of a new entrant, Telkom Mobile, which launched mobile services late in 2010, and in addition without Cell C, which launched services in around 2002. Second, we simulate a counterfactual situation without the regulation of termination rates which took place between 2010 and 2014.

Based on our equilibrium model, without the entry of Telkom Mobile and Cell C, we find that the adoption of mobile phones in South Africa would be lower by about two percentage points on average over the period 2011-2014. Thus, entry led to a relatively small increase in the total number of adopters, though this effect is higher for low-income consumers. Without entry, mobile penetration among high-income consumers would have been two percentage points lower, while the reduction in penetration among low-income consumers would have been four percentage points. We also use the model to simulate changes in consumer welfare for different income groups and segments of society. In this way, we test whether poor or rich consumers benefit more from competition and regulation of firms with market power. We find that rich people benefited more from entry and regulation in terms of changes in consumer surplus. Thus, we find that entry does not reduce inequality but has the opposite effect. We also find that entry has a limited impact on consumer surplus. Furthermore, we find that regulation of MTRs results in significantly lower prices. Similarly, high-income consumers benefit from a larger increase in consumer surplus. In addition, we find that regulation has a greater effect than competition does on mobile penetration. In particular, absent regulation over the period between 2011 and 2014, mobile penetration would have been eight percentage points lower among low-income consumers compared to four percentage points among high-income consumers.

Our results provide important evidence on the distributional effects of competition and regulation, which can be of use to policy makers in South Africa and other countries.[11] We show that

[11] Gruber and Koutroumpis (2011) show that higher penetration of mobile phones has a positive impact on economic growth. Other papers on the impact of mobile phones on market outcomes include Jensen (2007), Aker

a ‘rising tide lifts all boats’, in that bringing about lower prices through competition and regulation benefits all consumers. However, the distribution of these benefits, measured by changes in consumer surplus, is skewed towards higher-income consumers and residents in towns and cities. Policymakers need to consider means by which new entrants could be encouraged to focus on low-income consumers and on rural areas.

The remainder of the article is organized as follows. Section 3.2 discusses relevant literature. Section 3.3 describes the market being analysed. Section 3.4 presents the data which we use in the estimation. Section 3.5 introduces the econometric framework. Section 3.6 presents the estimation results and finally, Section 3.7 concludes.

### 3.2 Literature review

Our paper contributes to various streams of the literature. First, we estimate demand for telecommunications using a discrete-choice model, a common approach used in previous research to estimate price elasticities and the effects of entry. For example, Train et al. (1987) use data from a US household survey and develop a nested logit model of consumer choices of telephone services. Price elasticities are estimated for a number of service options which vary based on distance. They find relatively high elasticities for monthly charges, which suggests that the service options are substitutes for one another. Pereira and Ribeiro (2011) use a mixed-logit model to estimate price elasticities for broadband Internet access using data from a household survey in Portugal. They then simulate the price effects of the structural separation of the incumbent dual-owner of DSL and cable broadband, and find substantial gains to consumers from doing so. In another paper, Grzybowski et al. (2014) estimate demand for fixed and mobile broadband services in Slovakia using a random coefficients model. They use their estimates of price elasticities to define markets, and conclude that fixed and mobile broadband are in the same market. However, we are aware of only one paper, by Björkegren (2018), in which a structural demand model is estimated for an African country, in Rwanda. In that paper, the author estimates changes in consumer welfare if taxes were shifted from handsets to usage of mobile phones. He finds, due to network effects in the adoption of mobile services, that welfare would have been 38% higher.

and Mbiti (2010), and Muto and Yamano (2009).

Second, we contribute to the literature on the impact of mobile telecommunications services on welfare and economic development using micro-level data. For example, Jensen (2007) analyses the impact of the rollout of mobile services in Kerala in India on the dispersion of prices for fish sold by fishermen at coastal markets. He finds that price dispersion decreased considerably and that this improved welfare for fishermen and consumers. In a related paper, Aker (2010) evaluates the effects of the expansion of mobile phone coverage in Niger on grain-price dispersion. She finds lower price dispersion between grain markets as mobile coverage expanded between 2001 and 2006, resulting in lower search costs.

Muto and Yamano (2009) use household panel data to analyse the effects of the expansion of mobile networks on the sale of agricultural commodities in Uganda between 2003 and 2005. They find that sales of perishable commodities (bananas) grew as a result of greater market participation by producing households due to expanded mobile coverage. In a related paper, Muto (2012) uses the same dataset to assess the effects of mobile phone ownership on individual choices to migrate in Uganda. He finds that mobile phone ownership results in a higher likelihood of migrating. Klonner and Nolen (2010) analyse operator and survey data to evaluate the effects of the rollout of mobile networks on unemployment in South Africa. Their results show significantly higher employment rates after an area receives mobile network coverage.

Aker and Mbiti (2010) survey the evidence on the impact of mobile telephony on economic development in Sub-Saharan Africa, and conclude that the expansion in mobile usage improves consumer and producer welfare. Finally, Hjort and Poulsen (forthcoming) assess the impact of the arrival of high-speed broadband via subsea internet cables on employment and productivity in African countries and find that they rise with access to high-speed broadband.

Third, our paper is also related to the literature on the impact of entry and regulation on prices and welfare in markets for telecommunications services. Nicolle et al. (2018) use hedonic price regressions to analyse the impact of regulation and investment on prices for mobile services in France. They find that quality-adjusted prices declined between May 2011 and December 2014 which was mainly due to new entry and investment in 4G networks. Economides et al. (2008) quantify the benefits of entry into local telecommunications service markets. They find that consumers benefit significantly, though rather than resulting in reduced prices, entry results in product differentiation and new plan introductions. In another paper, Genakos et al. (2018)

study the impact of market concentration levels on prices and investment in 33 OECD countries in the years between 2002 and 2014. They report that prices and concentration are positively related and that increased concentration may lead to higher investment.

In respect of the impact of regulation on prices and welfare, gains from MTR regulation have been reported on previously such as in Genakos and Valletti (2015). However, as far as we are aware, there are no studies that comment on gains from MTR regulation in respect of consumer surplus in a structural framework. Stork and Gillwald (2014) discuss the impact of termination rate reductions in Kenya, Namibia and South Africa. They conclude that lower MTRs resulted in lower retail prices and greater expansion of mobile services to differing degrees. While prices fell rapidly in Kenya in response to lower MTRs, retail price reductions were slower in Namibia and South Africa. This paper is based on a qualitative approach, however.

Fourth, we contribute to the literature on the impact of competition on inequality and on welfare more generally. This is important in light of recent calls for a greater role for competition policy in reducing inequality (see Baker and Salop, 2015). In a seminal paper, Deaton (1988) proposes a methodology to estimate elasticities of demand using household survey data. The purpose of their analysis was to improve the design of taxes and subsidies for commodities in developing country governments, where the government is not able to raise general income taxes. Argent and Begazo (2015) show that reducing sugar and maize prices by 20% by making markets more competitive in Kenya could result in a reduction in poverty of between 1.5% (sugar) and 1.8% (maize). However, competition may not always benefit market participants belonging to different income groups equally, and thus can affect inequality. For example, Wodon and Zaman (2009) find that lower food prices would benefit higher-income consumers at the expense of poor producers.

In highly unequal economies, firms may enter the market and compete for high-income consumers, where they can earn higher margins, rather than provide services at low margins to masses of poor consumers. However, from a welfare perspective, poor consumers should benefit the most from access to telecommunications services, which may help them to get jobs and escape poverty. In this paper, we detail how entry and regulation impact the well-being of South African consumers in different income and societal segments. Our paper presents important evidence on the distributional effects of government policies towards competition and regulation in telecommunications markets in South Africa and other developing economies with high levels of inequality. We find that the regulation of MTRs is a more effective tool for reducing prices than competition by means of new entry.

### 3.3 Industry

There are two full-coverage mobile network operators in South Africa, MTN and Vodacom, and two partial-coverage networks, Telkom Mobile and Cell C. The latter two roamed on the MTN and Vodacom networks respectively in the sample period.[12]

Vodacom and MTN began rolling out their Global System for Mobile (GSM) networks in the mid-1990s, at around the same time that similar networks were being rolled out in other countries. Cell C entered the market in late 2001, while Telkom Mobile entered in late 2010. Cell C and Telkom Mobile focus largely on higher-income cities and towns. As a result of this, the newer entrants have largely captured higher-income consumers (see Figure 7). The newer entrants had poorer quality networks, due to the lack of seamless roaming and because 3G and 4G roaming was not available, at least in the earlier years in the sample period.

As a result of racial discrimination during apartheid, White consumers have significantly higher incomes compared to other racial groups. Indian and Coloured consumers were discriminated against during apartheid but benefited from having more access to public resources and from living in urban areas. Many Black people were forced to live in rural 'homelands' with substantially lower funding for education and healthcare. Indian and Coloured consumers therefore have lower incomes than White consumers though all three groups have higher incomes than Black consumers.

Based on our data, operator market shares vary by race and income group (see Figure 7). There are nine provinces in South Africa which have very different population groups. The provinces of the Western Cape and Gauteng have significantly more people living in urban areas, while the provinces of the Eastern Cape, KwaZulu-Natal, Limpopo, Mpumalanga and the North-West have large populations living in former 'homelands' which are largely rural areas. The Northern Cape is a sparsely populated province that has a relatively small population.

[12] We dropped subscribers to Virgin Mobile, a Mobile Virtual Network Operator (MVNO), from the analysis due to its small market share which was much below 1% in 2014. In an alternative specification, we estimated a model with subscribers to Virgin Mobile and include this provider in the choice set of all consumers. The estimation results are comparable.

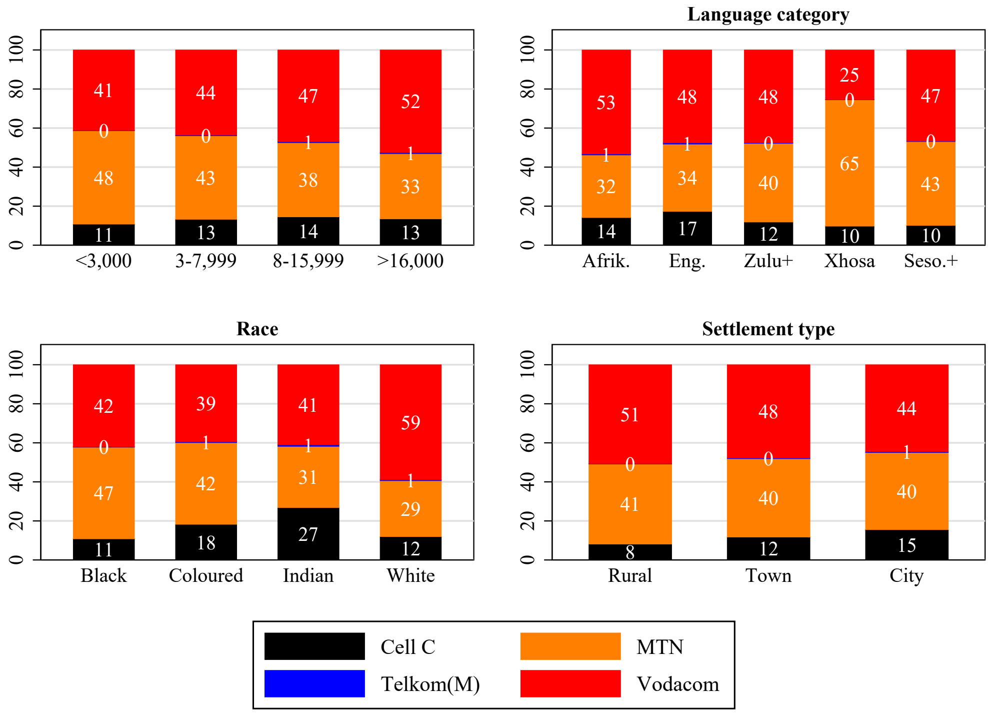



**Figure 7: Operator market shares by demographic segments (AMPS, 2009-2014)**

Source: AMPS survey market shares for all observations over the period 2009-2014.

There are eleven official languages in South Africa which are, ranked by number of speakers: Zulu, Xhosa, Afrikaans, English, Northern Sotho, Tswana, Sesotho, Tsonga, Swazi, Venda and Ndebele. In the dataset, languages sharing common traits or a common geographic region are grouped together. Thus, Zulu is grouped with Swazi and Ndebele ('Zulu+'), while Sesotho, the main language spoken in the largest cities of Johannesburg and Pretoria is grouped together with Northern Sotho, Tswana, Tsonga and Venda ('Sesotho+').

Mobile network choices among language groups follow race group patterns.[13]

Cell C and Telkom Mobile have largely focused on urban areas, and their market shares are therefore relatively higher in cities and towns (see Figure 7). Low-income consumers based in rural areas have not taken up new entrant services, despite the new entrants having roaming agreements with the full-coverage networks.

Termination rates are an important cost factor for voice services on mobile networks, as

[13]Note that Indian consumers largely speak English, while approximately three-quarters of Coloured consumers speak Afrikaans.

they are the charges that each operator pays for calls to other networks. The government and Independent Communications Authority of South Africa (ICASA), the telecommunications sector regulator, began reducing mobile termination rates (MTRs) in 2010. At that stage Telkom Mobile, owned partly by government, complained about high MTRs due to their imminent entry.[14] Since then, MTRs have declined by 90% and retail voice prices have declined as a result of this, according to ICASA (see Figure 8).[15] There are separate ('asymmetrical') termination rates for large and small operators, as the regulations allow smaller operators to charge a higher MTR. There were separate peak and off-peak termination rates until 2013, when the regulations forced the MTRs to converge.

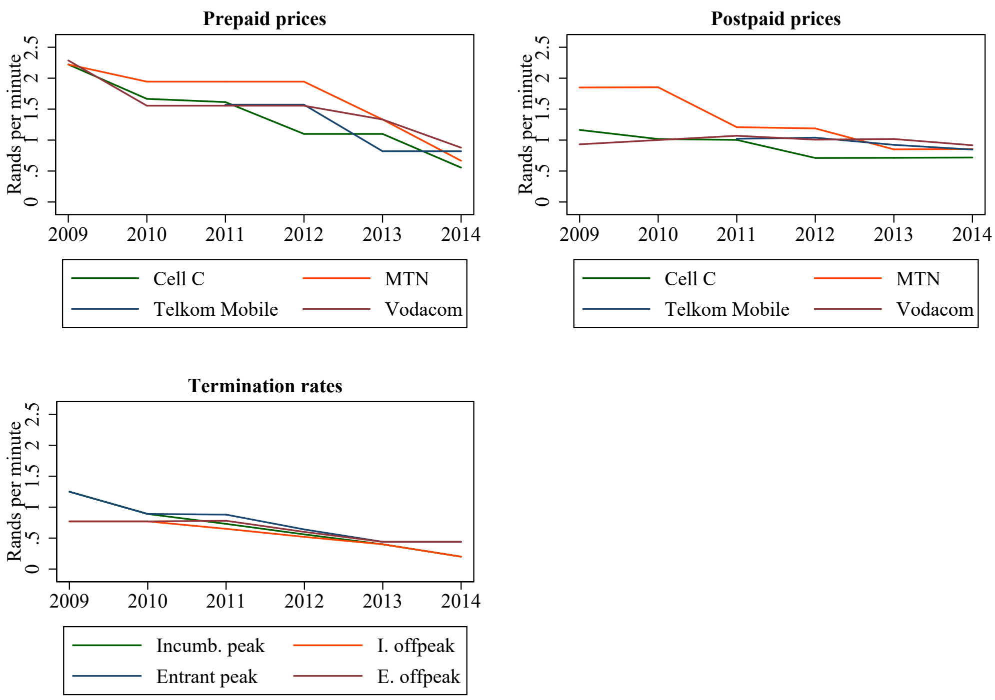



**Figure 8: Average operator prices and termination rates (2009-2014)**

Sources: Prices from Research ICT Africa, Tarifica and the Internet Archive and termination rates from government gazettes.

[14]Dividends from Telkom appear on the budget in the telecommunications line ministry's annual report, and appear to account for the bulk of incoming funds into that ministry.

[15]ICASA reviewed the effects of lower MTRs in its bi-annual review of prices. See: ICASA, 2018, "Bi-Annual report on the analysis of tariff notifications submitted to ICASA for the period 02 January 2018 to 30 June 2018".

### 3.4 Data

We estimate a discrete-choice model using six waves of the All Media Products Survey (AMPS). AMPS is a survey of approximately 25,000 consumers each year between 2009 and 2014.[16] In total, the sample size is more than 134,000 observations. The AMPS dataset contains consumer choices of a range of products and services as well as personal and household characteristics.[17] As can be expected, low-income consumers account for the bulk of survey respondents and are disprorportionately less likely to be connected (see Table 5).

Prices were obtained from Research ICT Africa and Tarifica.[18] In addition, we used an online archive service, the Internet Archive's Wayback Machine, to complete the pricing database.[19] Prices were matched to consumers firstly by payment method (prepaid and postpaid).[20] Second, we matched prices using estimated usage of voice minutes. In this way, we arrived at a price per minute for each operator faced by each consumer.

Prepaid consumers, which account for 81% of the sample with a mobile service, belong to one segment. Postpaid consumers, which account for the balance, were divided into three groups: low, medium and high voice users according to their declared monthly cellphone spend. Low-usage consumers are assumed to have monthly bills in the range R1-R150 per month, medium-usage is in the range R151-500 and high-usage is above R500 per month.[21]

[16] An exception is the year 2013, when only half that number is available due to a questionnaire change halfway through the year. This meant that certain questions (such as cellphone spend) were not asked in the second half of the year, which means it was not possible to use those observations.

[17] This is an annual survey conducted by the South African Advertising Research Foundation (SAARF) 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.

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

[19] The Internet Archive, whose website is archive.org, is a non-profit organisation that records snapshots of websites over time and makes these available to the public.

[20] In South Africa, most subscribers are on prepaid plans and are typically unable to choose between prepaid and postpaid because they do not meet the income and employment requirements for a postpaid contract. This is a result of low levels of employment and participation in the labour force. According to the "Quarterly Labour Force Survey" undertaken by Statistics South Africa (publication P0211), the employed population divided by the number of adults in South Africa (aged 15-65 years), i.e. the 'labour absorption rate', varied between 41% and 46% over the period between 2009 and 2014. The unemployment rate varied between 22% and 26% using the official definition (active job seekers) while the expanded definition (i.e. including discouraged work seekers) varied between 30% and 36%.

[21] The South African currency is highly volatile but as of December 2018 one US dollar was approximately 14.6 Rands. Classifying consumers into high, medium and low usage groups is a standard approach to segmenting telecommunications subscribers. The spending bands were selected to broadly reflect regular intervals and available mobile packages, and so as to ensure a large number of observations would fall within each category. Approximately 25% of postpaid customers fall within the first group, around 53% fall within the second category and the remaining 22% fall within the highest spend group. The second category has a greater proportion since

**Table 5: AMPS demographic variables, by operator (entire sample)**

| Variable | None | | Cell C | | MTN | | Telkom(M) | | Vodacom | | N |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | % | N | % | N | % | N | % | N | % | |
| **Income** | | | | | | | | | | | |
| <R3,000 | 9,821 | 31 | 2,351 | 7 | 10,453 | 33 | 51 | 0 | 8,979 | 28 | 31,655 |
| R3-7,999 | 7,274 | 19 | 4,160 | 11 | 13,425 | 35 | 114 | 0 | 13,676 | 35 | 38,649 |
| R8-15,999 | 3,918 | 12 | 4,302 | 13 | 11,281 | 34 | 161 | 0 | 13,937 | 41 | 33,599 |
| >R15,999 | 1,943 | 6 | 4,228 | 13 | 10,512 | 31 | 199 | 1 | 16,511 | 49 | 33,393 |
| **Race** | | | | | | | | | | | |
| Black | 12,244 | 17 | 6,368 | 9 | 27,641 | 39 | 177 | 0 | 24,717 | 35 | 71,147 |
| Coloured | 5,122 | 26 | 2,697 | 14 | 6,185 | 31 | 93 | 0 | 5,810 | 29 | 19,907 |
| Indian | 1,585 | 17 | 2,013 | 22 | 2,359 | 26 | 64 | 1 | 3,079 | 34 | 9,100 |
| White | 4,005 | 11 | 3,963 | 11 | 9,486 | 26 | 191 | 1 | 19,497 | 52 | 37,142 |
| **Language** | | | | | | | | | | | |
| Afrikaans | 6,935 | 19 | 4,278 | 11 | 9,715 | 26 | 172 | 0 | 16,125 | 43 | 37,225 |
| English | 4,073 | 13 | 4,804 | 15 | 9,559 | 30 | 197 | 1 | 13,187 | 41 | 31,820 |
| Zulu+ | 3,306 | 16 | 2,121 | 10 | 7,223 | 34 | 63 | 0 | 8,514 | 40 | 21,227 |
| Xhosa | 3,618 | 23 | 1,205 | 8 | 8,002 | 50 | 20 | 0 | 3,140 | 20 | 15,985 |
| Sotho+ | 5,024 | 16 | 2,633 | 8 | 11,172 | 36 | 73 | 0 | 12,137 | 39 | 31,039 |
| **Settlement type** | | | | | | | | | | | |
| Rural | 5,085 | 24 | 1,340 | 6 | 6,776 | 31 | 46 | 0 | 8,363 | 39 | 21,610 |
| Town | 8,334 | 18 | 4,485 | 10 | 15,354 | 33 | 148 | 0 | 18,265 | 39 | 46,586 |
| City | 9,537 | 14 | 9,216 | 13 | 23,541 | 34 | 331 | 0 | 26,475 | 38 | 69,100 |
| **Province** | | | | | | | | | | | |
| Western Cape | 3,337 | 18 | 2,335 | 13 | 6,167 | 34 | 86 | 0 | 6,479 | 35 | 18,404 |
| Northern Cape | 1,891 | 28 | 743 | 11 | 1,821 | 27 | 17 | 0 | 2,295 | 34 | 6,767 |
| Free State | 1,726 | 16 | 958 | 9 | 3,901 | 36 | 32 | 0 | 4,243 | 39 | 10,860 |
| Eastern Cape | 4,866 | 25 | 1,743 | 9 | 8,113 | 42 | 55 | 0 | 4,340 | 23 | 19,117 |
| Kwazulu-Natal | 3,992 | 16 | 3,867 | 15 | 8,045 | 32 | 101 | 0 | 9,178 | 36 | 25,183 |
| Mpumalanga | 786 | 11 | 485 | 7 | 1,812 | 26 | 21 | 0 | 3,962 | 56 | 7,066 |
| Limpopo | 1,303 | 17 | 585 | 7 | 2,042 | 26 | 20 | 0 | 3,897 | 50 | 7,847 |
| Gauteng | 3,870 | 11 | 3,737 | 11 | 11,173 | 32 | 180 | 1 | 15,741 | 45 | 34,701 |
| North-West | 1,185 | 16 | 588 | 8 | 2,597 | 35 | 13 | 0 | 2,968 | 40 | 7,351 |
| **Age category** | | | | | | | | | | | |
| Age < 26 years | 6,505 | 16 | 5,504 | 14 | 13,909 | 35 | 125 | 0 | 14,033 | 35 | 40,076 |
| Age 26-50 years | 7,158 | 12 | 6,631 | 11 | 21,850 | 36 | 289 | 0 | 24,885 | 41 | 60,813 |
| Age 51-65 years | 4,618 | 20 | 2,065 | 9 | 6,999 | 30 | 82 | 0 | 9,705 | 41 | 23,469 |
| Age > 65 years | 4,675 | 36 | 841 | 7 | 2,913 | 23 | 29 | 0 | 4,480 | 35 | 12,938 |
| **Additional** | | | | | | | | | | | |
| Unemployed | 18,228 | 22 | 8,941 | 11 | 25,954 | 31 | 276 | 0 | 29,244 | 35 | 82,643 |
| Employed | 4,728 | 9 | 6,100 | 11 | 19,717 | 36 | 249 | 0 | 23,859 | 44 | 54,653 |
| Not self-empl. | 21,998 | 18 | 13,678 | 11 | 41,229 | 33 | 448 | 0 | 46,881 | 38 | 124,234 |
| Self-employed | 958 | 7 | 1,363 | 10 | 4,442 | 34 | 77 | 1 | 6,222 | 48 | 13,062 |
| No home tel. | 17,186 | 17 | 10,945 | 11 | 35,415 | 35 | 331 | 0 | 37,681 | 37 | 101,558 |
| Home telephone | 5,770 | 16 | 4,096 | 11 | 10,256 | 29 | 194 | 1 | 15,422 | 43 | 35,738 |
| No work tel. | 22,216 | 18 | 13,195 | 11 | 40,600 | 33 | 450 | 0 | 46,342 | 38 | 122,803 |
| Work telephone | 740 | 5 | 1,846 | 13 | 5,071 | 35 | 75 | 1 | 6,761 | 47 | 14,493 |
| Female | 10,681 | 16 | 7,386 | 11 | 23,618 | 34 | 217 | 0 | 26,919 | 39 | 68,821 |
| Male | 12,275 | 18 | 7,655 | 11 | 22,053 | 32 | 308 | 0 | 26,184 | 38 | 68,475 |

Next, we computed average prices per minute for the four consumer segments. Prices for prepaid and postpaid services are shown on Figure 8. We assumed different monthly usage volumes for each segment: 30 minutes for prepaid users (1 minute per day), 180 for low-usage postpaid consumers (6 per day), 540 for medium-usage postpaid consumers (18 per day) and 1,080 for high-usage postpaid consumers (36 per day).[22] In South Africa, prices differ depending on whether calls are on the same network (on-net), to other mobile networks (off-net) or are terminated on fixed lines. We assumed that 10% of minutes are terminated on fixed lines and 90% are terminated on mobile networks, for all consumers. Calls terminated on mobile networks are distributed according to operator market shares. We also assumed that 50% of calls are made in 'peak' periods and 50% were 'off-peak', for which there are different prices.[23] Using this call distribution pattern, we computed the average price per minute for all prepaid tariffs and picked the lowest for each operator in a given year. We assume that these are the prices that prepaid consumers face when choosing a service. In a similar way, we computed the average price per minute faced by postpaid consumers belonging to the three segments. We tested our results against different calling patterns and our estimates of elasticities are comparable in these different specifications. Usage profiles are a common means of modelling consumer decisions in telecommunications services as well as comparing prices across countries and over time.[24]

We tested the proposition that new entrants choose higher-income areas in towns and cities by means of reduced-form regressions on a proxy for entry, the Herfindahl-Hirschman Index (HHI).[25] A lower HHI indicates a greater degree of entry. As we can expect, new entrants focus

almost 25% of postpaid customers spend between R271-R500 per month. Since there are many more packages advertised in the R151-R500 spend level than above R500, it made more sense to allocate the R271-R500 category to the medium-spend group.

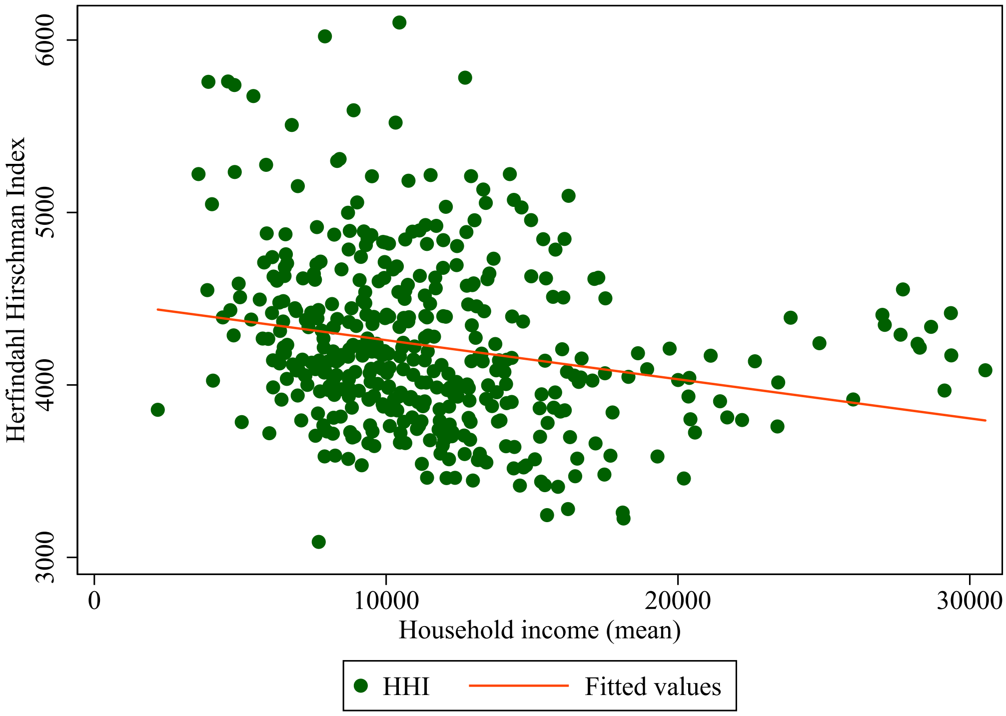
[22]These usage categories are similar to the OECD mobile voice call baskets cited below, of 30, 100, 300 and 900 calls per month. The groups are also not far from minutes of use reported by Vodacom in its annual reports between 2009 and 2014, for example, for prepaid and postpaid customers. Prepaid customers on the Vodacom network used between 52 minutes and 116 minutes per month on average, depending on the year, while postpaid consumers used between 182 and 240 minutes per month.

[23]This is in line with the OECD usage baskets mentioned above, which assume that 46% of calls are made during the day, 27% are made during the evening and 27% over the weekend. In South Africa, weekend and evening calls are grouped together under the 'off-peak' period. Source: OECD, 2017, "Revised OECD Telecommunications Price Baskets".

[24]See, for example, the OECD basket methodology, cited above.

[25]The HHI is calculated as follows: $HHI = \sum_{j=1}^{k} (s_j * 100)^2$, where $s_j$ is the market share of operator $j$. A monopoly results in an HHI of 10,000 ($100^2$). AMPS reports the locations of respondents in each year by province, by parts of the large cities of Cape Town, Durban, Johannesburg and Pretoria, by secondary cities and towns (Bloemfontein, Kimberley, Pietermaritzburg, Port Elizabeth, East London, Vaal) and by community size (metropolitan areas (250 000+), cities (100 000 - 249 999), large Towns (40 000 - 99 999), small towns (8 000-39 999), large villages (4 000- 7 999), small villages (500 -3 999), settlements (less than 500), non-urban (rural)).

**Figure 9: Relationship between market concentration (HHI) levels and income (2009-2014)**




HHI calculated from AMPS sample (N = 420).

on areas that have a higher share of richer consumers (see Figure 9 and Table 6). Market concentration levels are lower in towns and cities, and among high-income consumers, whether measured by mean household incomes or the share of high-income individuals in a location. Income, race and language group are correlated in South Africa. Therefore, higher-income races (Coloured, Whites, Indians) experience lower levels of market concentration, and a similar pattern is found among higher-income language groups (English and Afrikaans-speakers). This suggests that new entrants target higher-income locations and population groups.

## 3.5 Econometric Model

### 3.5.1 Demand

#### Discrete choice model

We estimate demand for mobile subscriptions by means of a discrete-choice model, where

In total, there are 509 such location-years. We dropped location-years that had fewer than 50 observations, and arrive at a sample size of 420.

**Table 6: Relationship between market concentration (HHI) and income measures**

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| | b/se | b/se | b/se | b/se |
| Towns | -311.28*** | -318.98*** | -236.02*** | -249.74*** |
| | (68.77) | (68.46) | (62.45) | (62.64) |
| Cities | -408.07*** | -424.06*** | -276.15*** | -221.09** |
| | (80.50) | (78.82) | (73.41) | (76.02) |
| Household income (mean) | -0.01* | | -0.00 | 0.01+ |
| | (0.01) | | (0.01) | (0.01) |
| High income % of population | | -360.27+ | | |
| | | (183.39) | | |
| Coloured % of population | | | -724.27*** | |
| | | | (107.89) | |
| White % of population | | | -376.44* | |
| | | | (180.03) | |
| Indian % of population | | | -2074.03*** | |
| | | | (239.04) | |
| English % of population | | | | -1333.12*** |
| | | | | (138.78) |
| Afrikaans % of population | | | | -402.52*** |
| | | | | (90.80) |
| Constant | 4660.84*** | 4615.95*** | 4805.16*** | 4712.46*** |
| | (75.63) | (66.47) | (72.83) | (76.20) |
| R-Square | 0.11 | 0.11 | 0.29 | 0.28 |
| Number of obs | 420 | 420 | 420 | 420 |

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

Note that the shares of race groups in the AMPS sample are as follows: Black (51.8%), Coloured (14.5%), Indian (6.6%), White (27%).

consumers choose the network operator that maximizes their utility function. We allow individuals $i = 1, ..., N$ to choose among network operators $j = 1, ..., J$. Individual utility depends on network and consumer characteristics. In what follows, we skip the time subscript for year $t$. We specify that individual $i$'s utility for mobile network $j$ is given by:

$$U_{ij} = x_j' \widetilde{\beta}_i - \widetilde{\alpha}_i p_{ij} + \epsilon_{ij}. \tag{4}$$

Here, $x_j$ is a $J \times 1$ vector of network dummy variables interacted with individual characteristics and $\widetilde{\beta}_i$ is a $J \times 1$ vector of coefficients denoting the individual-specific valuations for each network, estimated relative to the base of having no mobile service. Furthermore, $p_{ij}$ denotes the price paid by consumer $i$ for making a call on network $j$, and $\widetilde{\alpha}_i$ is a coefficient for the individual-specific valuation of price. The construction of the price variable was discussed in Section 3.4. Finally, $\epsilon_{ij}$ is an individual-specific valuation for network $j$, i.e. the "logit error term". It is identically and independently distributed across mobile networks according to the Type I extreme value distribution.

The vector of coefficients $\widetilde{\beta}_i$ and the price coefficient $\widetilde{\alpha}_i$ may depend on observed individual characteristics and unobserved heterogeneity. More specifically, we define:

$$\begin{pmatrix} \widetilde{\beta}_i \\ \widetilde{\alpha}_i \end{pmatrix} = \begin{pmatrix} \beta \\ \alpha \end{pmatrix} + \Pi D_i + \begin{pmatrix} 0 \\ \sigma_\alpha \end{pmatrix} \nu_i \quad , \qquad \nu_i \sim N(0,1) \tag{5}$$

where $(\beta, \alpha)$ refers to a $(J+1) \times 1$ vector of mean valuations. The vector of observable individual characteristics, $D_i$, has dimension $d \times 1$. The matrix of parameters $\Pi$ with dimension $(J+1) \times d$ captures the impact of individual characteristics on the valuations for the $J$ network dummy variables, $x_{jt}$, and the price variable, $p_{jt}$. The randomly drawn vector from the standard normal distribution $\nu_i$ captures unobserved individual heterogeneity in respect of price. In addition, $\sigma_\alpha$ is a vector of standard deviations around the mean valuations.

The vector of observable characteristics $D_i$ includes gender, age category ($15-25$, $26-50$, $51-65$, 66 and above), race, language, province, income group (below R$3,000$, R$3,000-7,999$, R$8,000-15,999$, R$16,000$ and above, per month), employment status, whether the person is self-employed and whether the person has a telephone at home or work.

In the special case, where $\sigma_\alpha = 0$, there is no unobserved individual heterogeneity and we obtain the conditional logit model. In a more general framework, we have a mixed or random coefficients logit model, which allows for unobserved heterogeneity between individuals. The utility function specified above allows for flexible substitution between network operators. This allows us to assess which network operators are closer substitutes at the level of the individual.

An individual $i$ chooses a utility-maxmizing network $j$, i.e. $U_{ij} = \max_{k \in C_i} U_{ik}$, where $C_i$ is individual $i$'s available choice set. Hence, the probability that individual $i$ with given coefficients $\widetilde{\beta}_i$ and $\widetilde{\alpha}_i$ chooses network $j$ is given by:

$$
\begin{aligned}
l_{ijt}\left(\widetilde{\beta}_i, \widetilde{\alpha}_i\right) &= \Pr\left(U_{ij} = \max_{k \in C_i} U_{ik}\right) \\
&= \frac{\exp\left(x_j'\widetilde{\beta}_i - \widetilde{\alpha}_i p_{ij}\right)}{\sum_{k \in C_i} \exp\left(x_k'\widetilde{\beta}_i - \widetilde{\alpha}_i p_{ik}\right)}
\end{aligned}
$$

where the second line arises from the distributional assumptions of the logit error term $\epsilon_{ij}$. In the random coefficients model we need to integrate the conditional choice probability $l_{ij}\left(\widetilde{\beta}_i, \widetilde{\alpha}_i\right)$ over the distribution of $\widetilde{\alpha}_i$:

$$
P_{ij} = \int_{\widetilde{\alpha}} l_{ij}\left(\widetilde{\beta}_i, \widetilde{\alpha}\right) f(\widetilde{\alpha}) d\widetilde{\alpha}, \tag{6}
$$

The distribution of $\widetilde{\alpha}_i$ was specified earlier in (5) and consists of an observable part and an unobservable component that is normally distributed, $\nu_i \sim N(0,1)$.

Assuming independence of individual choices, the log-likelihood function can be written as:

$$
\mathcal{L}(\theta) = y_{ij} \sum_i^N \sum_j \log(P_{ij}). \tag{7}
$$

Here, $y_{ij} = 1$ if individual $i$ chose alternative $j$ and $y_{ij} = 0$ otherwise, and $\theta$ is the vector of all parameters to be estimated. We use a simulation method to approximate the integral entering the choice probabilities $P_{ij}$ in (6). Following Train (2009), we take $R$ draws for $\nu_i$ from the standard normal distribution to obtain the average choice probability per individual:

$$
\widehat{P}_{ij} = \frac{1}{R} \sum_{r=1}^{R} \frac{\exp\left(x_j'\beta - (\alpha + \sigma\nu_i^r)p_{ij} + (x_j', p_{ij})\Pi D_i\right)}{\sum_{k \in C_i} \exp\left(x_k'\beta - (\alpha + \sigma\nu_i^r)p_{ik} + (x_k', p_{ik})\Pi D_i\right)}. \tag{8}
$$

In the special case of no unobserved individual heterogeneity ($\sigma = 0$), Equation 8 becomes the multinomial choice probability:

$$\widehat{P}_{ij} = \frac{\exp\left(x_j'\beta - \alpha p_{ij} + (x_j', p_{ij})\Pi D_i\right)}{\sum_{k \in C_i} \exp\left(x_k'\beta - \alpha p_{ik} + (x_k', p_{ik})\Pi D_i\right)}.$$

Substituting Equation 8 for $P_{ij}$ in Equation 7, the maximum simulated likelihood estimator is the value of the parameter vector $\theta$ that maximizes the likelihood function $\mathcal{L}$.

**Price Elasticities of Demand**

We calculate own- and cross-price elasticities for voice calls on mobile networks in the following way. The effect of a one *percent* price increase by network $k$ on the *level* of individual $i$'s probability of choosing network $j$ is:

$$\frac{\partial P_{ij}}{\partial p_{ik}} p_{ik} = \begin{cases} -\widetilde{\alpha}_i P_{ij}(1 - P_{ij}) p_{ij} & \text{if k=j} \\ \widetilde{\alpha}_i P_{ij} P_{ik} p_{ik} & \text{otherwise} \end{cases}.$$

This could be referred to as individual $i$'s semi-elasticity of demand for $j$ with respect to the price of $k$. Let the aggregate market share for network $j$ be given by $s_j \equiv \sum_i P_{ij}/N$, where $N$ is the number of consumers in the dataset in a given year. The aggregate elasticity of demand for subscriptions to network $j$ with respect to the price of $k$ may then be defined as:

$$\varepsilon_{jk} = \frac{1}{N} \left( \sum_i \frac{\partial P_{ij}}{\partial p_{ik}} p_{ik} \right) \frac{1}{s_j} = \begin{cases} \sum_i (-\widetilde{\alpha}_i) P_{ij}(1 - P_{ij}) p_{ij} / \sum_i P_{ij} & \text{if k=j} \\ \sum_i \widetilde{\alpha}_i P_{ij} P_{ik} p_{ik} / \sum_i P_{ij} & \text{otherwise} \end{cases}. \quad (9)$$

**Consumer surplus**

We use the estimated model to calculate changes in consumer surplus due to regulation or new entry. In discrete-choice models, the expected consumer surplus of consumer $i$ is given by (see Small and Rosen, 1981):

$$E(CS_i) = \int_{\widetilde{\alpha}} \frac{1}{|\widetilde{\alpha}_i|} ln \left( \sum_j \exp(V_{ij}) \right) d\widetilde{\alpha} + C_i$$

where $\alpha_i$ is the individual-specific price coefficient, $V_{ijt}$ is the observed part of the utility function in Equation 4 and $C_i$ is an unknown constant representing unmeasured utility. The change in consumer surplus due to an intervention, such as regulating termination rates or introducing new entrants, can be written as:

$$\Delta E(CS_i) = \int_{\widetilde{\alpha}} \frac{1}{|\widetilde{\alpha}_i|} \left| ln\Big(\sum_j \exp(V_{ij}^1)\Big) - ln\Big(\sum_j \exp(V_{ij}^0)\Big) \right| d\widetilde{\alpha} \tag{10}$$

where $V_{ij}^1$ denotes the utility after and $V_{ij}^0$ before the intervention.

### 3.5.2 Supply

We use both the demand and supply-sides to simulate how the entry of mobile operators Cell C and Telkom Mobile impact welfare and how consumer surplus is distributed across consumer segments. For the simulations, we consider marginal costs to be call termination costs, calculated using the termination rates in Section 3.3.[26] We also simulate the effect of no regulatory intervention. In order to do this, we compute marginal costs as though the pre-regulation (pre-2010) mobile termination rates applied throughout the period between 2011 and 2014. In this simulation we consider that mobile operators compete by setting call prices per minute in prepaid and post-paid market segments separately. Prepaid consumers choose between prepaid offers from different operators but they do not switch to post-paid offers, and similarly post-paid consumers from each usage segment: low, medium and high.

The profits of firm $f$ are given by:

$$\Pi_f(\mathbf{p}) = (p_f - c_f)\, s_f(\mathbf{p}) L \tag{11}$$

where $c_f$ is the marginal cost of firm $f$, and $s_f(\mathbf{p})$ is firm $f$'s market share as a function of the price vector. Market size is denoted by $L$. Assuming that firms choose prices to maximize profits, the first-order conditions that define the Bertrand-Nash equilibrium are then given by:

$$s_f(\mathbf{p}) + (p_f - c_f)\, \frac{\partial s_f(\mathbf{p})}{\partial p_f} = 0. \tag{12}$$

for products $j = 1, \ldots, J$. The choice probabilities and price derivatives of choice probabilities

[26] We computed the termination costs for each mobile operator as follows. First, we consider that 90% of calls are made to other mobile networks (the other 10% are to fixed networks) and that calls to other mobile networks are distributed according to market shares. We further consider that 50% of calls are made during peak hours and 50% are made off-peak, since termination rates were different for these two time slots. Using this information, we computed an average termination cost per minute paid by each mobile operator in each year.

are computed at the individual level, and then an average is calculated for each of the four usage profiles (discussed in section 3.4) and for each operator and year. The FOCs can be written in vector notation as:

$$\mathbf{s}(\mathbf{p}) + (I \odot \mathbf{\Delta}(\mathbf{p}))\,(\mathbf{p} - \mathbf{c}) = 0. \tag{13}$$

where $\mathbf{p}$ and $\mathbf{s}(\mathbf{p})$ are $J \times 1$ price and market share vectors, $\mathbf{\Delta}(\mathbf{p}) \equiv \partial \mathbf{q}(\mathbf{p})/\partial \mathbf{p}'$ is a $J \times J$ matrix of own- and cross-price derivatives. A $J \times J$ block-diagonal identity matrix, $I$, represents ownership, and $\odot$ denotes element-by-element multiplication of two matrices.

The system of first-order conditions (Equation 13) can be used to perform counterfactual simulations. In the first simulation, we solve the system of equations after removing Telkom Mobile and Cell C from the market, which we do by setting their marginal costs (and equilibrium prices) to a very high number. The solution gives the counterfactual equilibrium price vector $\hat{\mathbf{p}}$, which contains only prices for the remaining mobile operators, Vodacom and MTN. In the second counterfactual, we use the pre-2010 termination rates as marginal costs. In the simulations, we calculate an average price per operator per year using the iterated best-response algorithm. We then use this price vector to compute the counterfactual market shares, $\hat{\mathbf{s}}$, and changes in individual consumer surplus given by Equation 10. These can then be aggregated for different population segments.

### 3.6 Results

When estimating the model we need to account for the endogeneity of the price variable. Consumer choices depend on price but are also determined by unobserved quality differences. At the same time, quality influences price. Following Petrin and Train (2010), we use the control function approach to account for this endogeneity.

In the first stage, we regress the prices on a set of controls. In particular, we use call termination charges to approximate the marginal cost of calls. Termination rates differ by destination and are zero for on-net calls. We compute the cost of termination based on the market shares of each operator. We apply the same split between calls to mobile (90%) and to fixed (10%), and between peak and off-peak (50% each), which we used in respect of usage profiles (Section 3.4). In the regression, we also use a set of dummy variables for operators and type of tariff, and their interaction terms. Our first-stage regression is shown in Table 7. The estimation results show that call termination costs have a significant impact on prices.

**Table 7: Control function estimation results - voice services**

| | | **Coeff.** | **(STD)** |
|---|---|---|---|
| Termination cost | | 1.30*** | (0.16) |
| MTN | | 0.80*** | (0.16) |
| Telkom | | 0.36* | (0.18) |
| Vodacom | | 0.50** | (0.16) |
| Prepaid | | 0.68*** | (0.16) |
| Postpaid* | Medium | 0.18 | (0.16) |
| | High | 0.44** | (0.16) |
| MTN* | Prepaid | -0.28 | (0.22) |
| | Postpaid medium | -0.21 | (0.22) |
| | Postpaid high | -0.22 | (0.22) |
| Telkom* | Prepaid | -0.42+ | (0.25) |
| | Postpaid medium | -0.21 | (0.25) |
| | Postpaid high | -0.27 | (0.25) |
| Vodacom* | Prepaid | -0.07 | (0.22) |
| | Postpaid medium | -0.14 | (0.22) |
| | Postpaid high | -0.19 | (0.22) |
| Constant | | -0.02 | (0.14) |
| Number of obs | 88 | | |
| R-squared | 0.68 | | |

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

An increase in termination cost by 1 cent increases the retail price by 1.3 cents. A positive relationship between call termination and retail prices was also found in earlier literature (see for instance Genakos and Valletti, 2015 and Hawthorne, 2018). We include the residuals from the first stage regression in our demand estimation to control for endogeneity.

The estimation results for the multinomial and random coefficients models are shown in Table 8. The price coefficient is highly significant and negative in both models. There is significant unobserved heterogeneity in responsiveness to price, shown by a significant standard deviation for the price variable. We also allow observable individual characteristics to determine price-responsiveness. Low-income consumers have a higher elasticity of demand than higher-income consumers. Black and Coloured consumers are less price-sensitive than White and Indian consumers, after controlling for income. Xhosa-speaking consumers are less price-sensitive.

Consumers who live in cities and towns are significantly more likely to choose Telkom and Cell C than Vodacom and MTN, after controlling for the quality of networks using operator dummy variables. Being employed, and self-employed in particular, as well as having a telephone at work

**Table 8: Estimation results**

| | Cond. logit Coeff. | (STD) | Mixed logit Coeff. | (STD) | Cond. logit Coeff. | (STD) | Mixed logit Coeff. | (STD) |
|---|---|---|---|---|---|---|---|---|
| Price | -2.14*** | (0.08) | -2.00*** | (0.09) | | | | |
| SD Price | | | 0.76*** | (0.03) | | | | |
| | **Price interactions** | | | | **Mobile interactions** | | | |
| Income 3-7,999 | 0.14*** | (0.03) | 0.23*** | (0.04) | 0.26*** | (0.06) | 0.24*** | (0.06) |
| Income 8-15,999 | 0.07* | (0.03) | 0.20*** | (0.04) | 0.79*** | (0.06) | 0.82*** | (0.07) |
| Income 16,000+ | 0.03 | (0.04) | 0.16*** | (0.04) | 1.27*** | (0.07) | 1.35*** | (0.07) |
| Black | 0.36*** | (0.07) | 0.50*** | (0.08) | -0.89*** | (0.13) | -1.15*** | (0.14) |
| Coloured | 0.26*** | (0.04) | 0.26*** | (0.04) | -1.20*** | (0.07) | -1.37*** | (0.07) |
| Indian | -0.24*** | (0.05) | -0.32*** | (0.06) | -0.59*** | (0.10) | -0.70*** | (0.10) |
| Afrikaans | -0.10 | (0.08) | -0.13 | (0.08) | 0.06 | (0.14) | 0.10 | (0.15) |
| English | 0.11 | (0.07) | 0.10 | (0.08) | 0.01 | (0.13) | 0.07 | (0.14) |
| Zulu+ | -0.03 | (0.04) | -0.03 | (0.04) | 0.02 | (0.07) | 0.02 | (0.08) |
| Xhosa | 0.57*** | (0.04) | 0.62*** | (0.05) | -0.90*** | (0.08) | -0.93*** | (0.08) |
| | **Operator fixed effects** | | | | **Operator * Cities** | | | |
| Cell C | 1.92*** | (0.15) | 2.08*** | (0.17) | 1.03*** | (0.04) | 1.11*** | (0.04) |
| MTN | 4.12*** | (0.16) | 4.14*** | (0.17) | 0.40*** | (0.03) | 0.49*** | (0.03) |
| Telkom | -1.13*** | (0.21) | -0.97*** | (0.22) | 1.16*** | (0.16) | 1.23*** | (0.16) |
| Vodacom | 4.04*** | (0.15) | 4.14*** | (0.17) | 0.26*** | (0.03) | 0.35*** | (0.03) |
| | | | | | **Operator * Towns** | | | |
| CellC | | | | | 0.62*** | (0.04) | 0.67*** | (0.04) |
| MTN | | | | | 0.27*** | (0.03) | 0.33*** | (0.03) |
| Telkom | | | | | 0.66*** | (0.17) | 0.71*** | (0.17) |
| Vodacom | | | | | 0.19*** | (0.03) | 0.25*** | (0.03) |
| | **Mobile interactions** | | | | | | | |
| Age 26-50 | 0.05** | (0.02) | 0.07** | (0.03) | | | | |
| Age 51-65 | -0.50*** | (0.02) | -0.61*** | (0.03) | | | | |
| Age 65+ | -1.25*** | (0.03) | -1.55*** | (0.04) | | | | |
| Male | -0.35*** | (0.02) | -0.43*** | (0.02) | | | | |
| Working | 0.54*** | (0.02) | 0.68*** | (0.03) | | | | |
| Self-employed | 0.25*** | (0.04) | 0.28*** | (0.05) | | | | |
| Telephone-home | -0.25*** | (0.02) | -0.30*** | (0.03) | | | | |
| Telephone-work | 0.53*** | (0.04) | 0.62*** | (0.05) | | | | |
| Western Cape | -0.05+ | (0.03) | -0.08+ | (0.04) | | | | |
| Northern Cape | -0.42*** | (0.04) | -0.51*** | (0.05) | | | | |
| Free State | 0.01 | (0.04) | 0.03 | (0.04) | | | | |
| Eastern Cape | -0.46*** | (0.03) | -0.59*** | (0.04) | | | | |
| KwaZulu Natal | -0.03 | (0.03) | -0.04 | (0.04) | | | | |
| Mpumalanga | 0.47*** | (0.05) | 0.57*** | (0.06) | | | | |
| Limpopo | 0.09* | (0.04) | 0.15** | (0.05) | | | | |
| North West | 0.07+ | (0.04) | 0.10+ | (0.05) | | | | |
| Control function | 1.78*** | (0.04) | 1.47*** | (0.04) | | | | |
| Number of obs | 636,891 | | 636,891 | | 636,891 | | 636,891 | |
| Log-likelihood | -166,357 | | -166,227 | | -166,357 | | -166,227 | |

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

**Table 9: Own-price & cross-price elasticities, by operator - prepaid (2011-2014)**

| Operator | Cell C | MTN | Telkom | Vodacom |
|---|---|---|---|---|
| Cell C | -1.44 | 0.77 | 0.01 | 0.76 |
| MTN | 0.19 | -1.38 | 0.01 | 0.73 |
| Telkom(M) | 0.21 | 0.77 | -1.77 | 0.75 |
| Vodacom | 0.19 | 0.76 | 0.01 | -1.22 |

**Table 10: Own-price & cross-price elasticities, by operator - postpaid (2011-2014)**

| Operator | Cell C | MTN | Telkom | Vodacom |
|---|---|---|---|---|
| Cell C | -1.13 | 0.59 | 0.01 | 0.81 |
| MTN | 0.21 | -1.17 | 0.01 | 0.81 |
| Telkom(M) | 0.22 | 0.60 | -1.64 | 0.81 |
| Vodacom | 0.21 | 0.60 | 0.01 | -0.92 |

Aggregate elasticities are calculated for each year between 2011 and 2014 (when Telkom Mobile was present). The elasticities shown on the table are the average over the four year period.

and being young all make it more likely to take up a mobile service. Being older than 50 and having a landline telephone at home makes taking up a mobile service less likely. There is some variability in the uptake of mobile services depending on the province; living in the Eastern, Western and Northern Cape provinces is associated with a lower probability of taking up a mobile service than being in Gauteng. Consumers in the North West, Limpopo and Mpumalanga are more likely to take up a mobile service than consumers in Gauteng.

We use the estimates to compute individual-level price elasticities and then aggregate them using the equations shown in Section 3.5.1. The demand for mobile services is relatively elastic in respect of prepaid prices, shown in Table 9 but somewhat less so in respect of postpaid services 10. The own-price elasticities of demand are the highest for Telkom Mobile's services, equal to -1.77 in respect of prepaid services for example. Vodacom faces the lowest own-price elasticity of demand. These are average elasticities for the period 2011-2014, since Telkom Mobile was in the market in these years. The cross-price elasticities show relatively small differences in the degree of substitution between mobile operators.

We use our demand estimates and termination costs to compute prices under the assumption of Nash-Bertrand equilibrium using equation (13). The marginal costs, average prices and mark-ups are shown fore prepaid prices in Table 11 and for postpaid prices (on average) in 12. Vodacom and MTN have the highest mark-ups (79%). Prices imputed from our model are similar to market prices. This means that our estimates of price elasticities are reasonable.

**Table 11: Operator prices, marginal costs and mark-ups - prepaid (2011-2014)**

| **Operator** | **Marginal costs** ZAR/min | **Market prices** ZAR/min | **Market mark-ups** % | **Model prices** ZAR/min | **Model mark-ups** % |
|---|---|---|---|---|---|
| Cell C | 0.41 | 1.09 | 63 | 1.09 | 63 |
| MTN | 0.29 | 1.47 | 79 | 1.30 | 77 |
| Telkom(M) | 0.46 | 1.20 | 62 | 1.06 | 58 |
| Vodacom | 0.27 | 1.33 | 80 | 1.23 | 78 |

**Table 12: Operator prices, marginal costs and mark-ups - postpaid (2011-2014)**

| **Operator** | **Marginal costs** ZAR/min | **Market prices** ZAR/min | **Market mark-ups** % | **Model prices** ZAR/min | **Model mark-ups** % |
|---|---|---|---|---|---|
| Cell C | 0.41 | 0.80 | 48 | 1.09 | 64 |
| MTN | 0.29 | 1.07 | 72 | 1.22 | 76 |
| Telkom(M) | 0.46 | 0.98 | 53 | 1.04 | 57 |
| Vodacom | 0.27 | 1.03 | 74 | 1.29 | 80 |

We consider termination costs to be marginal costs. Model prices are simulated from these costs using iterated best responses. Simple averages of prepaid and postpaid prices over 2011-2014 are shown.

We then simulate how entry and regulation affect consumer welfare in different population segments, in the following three counterfactuals. First, we remove Telkom Mobile from the market. Telkom had a market share of around three percent by 2014, having entered in 2011, which suggests a very small impact on consumer welfare. In the second case, we also remove Cell C from the market, which leaves just two main competitors, MTN and Vodacom. Cell C had a market share of around sixteen percent in 2014 and therefore had a much bigger impact on consumer welfare. Third, we simulate a ‘no regulation’ scenario, in which termination rates remain as they were in 2009. The simulations are conducted for the period between 2011 and 2014 using the iterated best responses algorithm.

In the first scenario, we find that the entry of Telkom Mobile had minimal impact on equilibrium prices and consumer surplus. In the absence of Telkom, the average welfare loss per minute is approximately one cent, which is very little compared to the average price of a call, which was approximately one Rand per minute.

In the second scenario, the average loss in consumer surplus in the absence of Cell C and Telkom is estimated at almost sixteen cents per minute, as shown in Table 13. If we assume that customers on average make 30 minutes of calls per month, which is the usage profile for prepaid customers, at an average price of R1.15 per minute, then an average’s customer’s bill

**Table 13: Change in prices & consumer surplus after entry & regulation (2011-2014)**

| | Model price | No Telkom, Cell C | | No regulation | | N |
|---|---|---|---|---|---|---|
| | | Price | $\Delta CS$ | Price | $\Delta CS$ | |
| **Income** | | | | | | |
| Income <3,000 | 1.08 | 1.11 | -0.12 | 1.30 | -0.21 | 18379 |
| Income 3-7,999 | 1.19 | 1.24 | -0.15 | 1.45 | -0.25 | 24610 |
| Income 8-15,999 | 1.25 | 1.32 | -0.17 | 1.53 | -0.27 | 21638 |
| Income >15,999 | 1.26 | 1.36 | -0.18 | 1.56 | -0.30 | 23080 |
| **Total** | 1.20 | 1.27 | -0.16 | 1.47 | -0.26 | 87707 |
| **Settlement type** | | | | | | |
| Rural | 1.16 | 1.21 | -0.11 | 1.40 | -0.23 | 13840 |
| Town | 1.20 | 1.26 | -0.14 | 1.46 | -0.25 | 29105 |
| City | 1.21 | 1.29 | -0.18 | 1.49 | -0.27 | 44762 |
| **Total** | 1.20 | 1.27 | -0.16 | 1.47 | -0.26 | 87707 |
| **Race** | | | | | | |
| Black | 1.23 | 1.29 | -0.17 | 1.49 | -0.26 | 45452 |
| Coloured | 1.09 | 1.12 | -0.13 | 1.34 | -0.23 | 12434 |
| Indian | 1.12 | 1.16 | -0.14 | 1.40 | -0.26 | 5925 |
| White | 1.22 | 1.30 | -0.16 | 1.50 | -0.28 | 23896 |
| **Total** | 1.20 | 1.27 | -0.16 | 1.47 | -0.26 | 87707 |
| **Language** | | | | | | |
| Afrikaans | 1.15 | 1.21 | -0.14 | 1.41 | -0.25 | 23620 |
| English | 1.19 | 1.27 | -0.17 | 1.48 | -0.28 | 20475 |
| Zulu, Swazi, Ndebele | 1.25 | 1.32 | -0.15 | 1.52 | -0.26 | 13511 |
| Xhosa | 1.16 | 1.21 | -0.21 | 1.40 | -0.24 | 10137 |
| Sth, Tsw, Tsn, Ven, Oth | 1.25 | 1.31 | -0.15 | 1.51 | -0.26 | 19964 |
| **Total** | 1.20 | 1.27 | -0.16 | 1.47 | -0.26 | 87707 |
| **Province** | | | | | | |
| Western Cape | 1.18 | 1.24 | -0.16 | 1.44 | -0.26 | 11882 |
| Northern Cape | 1.06 | 1.10 | -0.12 | 1.31 | -0.23 | 4307 |
| Free State | 1.22 | 1.29 | -0.15 | 1.49 | -0.26 | 6848 |
| Eastern Cape | 1.10 | 1.14 | -0.17 | 1.34 | -0.23 | 12172 |
| Kwazulu-Natal | 1.19 | 1.26 | -0.15 | 1.47 | -0.26 | 16042 |
| Mpumalanga | 1.29 | 1.36 | -0.14 | 1.56 | -0.28 | 4574 |
| Limpopo | 1.26 | 1.32 | -0.13 | 1.52 | -0.26 | 4998 |
| Gauteng | 1.25 | 1.33 | -0.18 | 1.53 | -0.28 | 22090 |
| North-West | 1.24 | 1.30 | -0.14 | 1.50 | -0.26 | 4794 |
| **Total** | 1.20 | 1.27 | -0.16 | 1.47 | -0.26 | 87707 |

Iterated best responses is used to simulate prices for each scenario in each year between 2011 and 2014. The simulations are run using termination costs as marginal costs, applying termination rates in 2009 for the whole period in the 'no regulation' scenario.

is R35 per month. In this case, the average gain from entry represents 14% of the bill and less than 1% of the average income of households (R9,758 per month). Overall, the consumer welfare effect of the entry of Telkom Mobile is close to zero while the welfare effect of the entry of Cell C is relatively small. The entrants did not price aggressively and were not able to acquire large market shares.

The increase in consumer surplus as a result of regulation was significantly larger at 26 cents per minute on average. Assuming, as above, a monthly average bill of R35 per month, regulation resulted in a consumer surplus gain of 23% of monthly bills but less than 1% of monthly incomes. While this gain is relatively small, the effect of regulation of termination rates resulted in a more meaningful impact than introducing new entrants. Previous research has also found gains from call termination rate regulation (such as by Genakos and Valletti, 2015). However, the effects on consumer surplus have not been quantified before as far as we are aware.

It is important to consider how consumer surplus from entry and regulation is distributed across income segments in the population. According to our estimates, the benefits of competition are not distributed equally in absolute terms. As shown in Table 13, the poorest consumers earning less than 3,000 Rands per month gained on average 12 cents per call. Consumers earning 16,000 Rands or more per month gained 18 cents per minute. Relative to usage intensity, since high-income consumers tend to use mobile services more intensively, they benefit even more. There are also differences in gains in consumer surplus across race groups, as shown in Table 13. Black people gain 17 cents per minute, Coloured people benefit on average 13 cents, Indian people gain 14 cents and White people gain 16 cents. We get a similar picture when computing changes in consumer surplus by language groups, as shown in Table 13. There are substantial geographic disparaties in the benefits from entry and regulation, which reflects the distribution of income in South Africa. While consumers surplus among city-dwellers increases by 18 cents per minute from entry, consumers in rural areas benefit by only 11 cents per minute. These results are consistent with our reduced-form analysis, which shows that entrants target geographic areas that have higher-income consumers (see Section 3.4).

The effects of regulation are also not evenly distributed. In the absence of regulation, consumer surplus among low-income consumers (earning less than R3,000 per month) declines by 21 cents per minute while those earning R16,000 or more per month lose 30 cents per minute.

There are also differences in losses between race and language groups, as shown in Table 13. Again, the geographic differences are significant, since consumers in rural areas benefit by approximately 23 cents per minute while mobile users in the city benefit from regulation by 27 cents per minute.

Next, we also use the model to simulate the impact of entry and regulation on mobile subscriptions in different population segments. We find that in the absence of Telkom, the uptake of mobile services over the period 2011-2014 does not change. In the absence of Telkom and Cell C, the penetration of mobile phones would be a bit lower, declining from 86% to 84%. As shown in Table 14, mainly poor people subscribed to mobile services after entry. Among people earning less than R3,000 per month, the lack of entry reduces penetration from 74% to 71%. At the same time, in the segment of people earning R16,000 and above, penetration declined from 95% to 93%. Entry also had divergent effects on subscriptions among people from different race and language groups. The increase in uptake as a result of entry (between 2 and 3 percentage points) was reasonably evenly spread across provinces and between urban and rural areas, likely as a result of the national pricing policies of the mobile operators. Therefore, competition introduced by new entrants to attract consumers in the towns and cities likely resulted in lower prices and greater uptake across South Africa.

The effects of regulation on the uptake of mobile services were more pronounced than the effects of entry, and again low-income consumers benefited more. Overall, mobile penetration absent regulation declines to 80% from 86% on average between 2011 and 2014. Without regulation, mobile penetration among low-income consumers would be 66% rather than 74%. Among high-income consumers, mobile penetration would have been 91% absent regulation rather than 95%. Thus, while high-income consumers benefit more from entry and regulation from a consumer surplus perspective, low-income consumers benefit more from a mobile uptake perspective. Our results suggest that introducing new entrants may be less important than direct interventions that support lower retail prices, such as lowering mobile termination rates.

### 3.7 Conclusion

We study the distributional welfare effects of entry and regulation in the mobile telecommunications sector in South Africa, which has the highest level of inequality in the world. We use

Table 14: **Impact of entry and regulation on mobile penetration (%, 2011-2014)**

| | Uptake - model prices | No Telkom, Cell C | No regulation | N |
|---|---|---|---|---|
| **Income** | | | | |
| Income <3,000 | 74 | 71 | 66 | 18379 |
| Income 3-7,999 | 84 | 81 | 77 | 24610 |
| Income 8-15,999 | 90 | 88 | 85 | 21638 |
| Income >15,999 | 95 | 93 | 91 | 23080 |
| **Total** | 86 | 84 | 80 | 87707 |
| **Settlement type** | | | | |
| Rural | 80 | 78 | 74 | 13840 |
| Town | 85 | 83 | 79 | 29105 |
| City | 89 | 86 | 83 | 44762 |
| **Total** | 86 | 84 | 80 | 87707 |
| **Race** | | | | |
| Black | 85 | 83 | 80 | 45452 |
| Coloured | 79 | 76 | 72 | 12434 |
| Indian | 86 | 82 | 78 | 5925 |
| White | 91 | 89 | 86 | 23896 |
| **Total** | 86 | 84 | 80 | 87707 |
| **Language** | | | | |
| Afrikaans | 85 | 82 | 78 | 23620 |
| English | 90 | 87 | 84 | 20475 |
| Zulu, Swazi, Ndebele | 87 | 85 | 82 | 13511 |
| Xhosa | 79 | 77 | 75 | 10137 |
| Sth, Tsw, Tsn, Ven, Oth | 87 | 84 | 81 | 19964 |
| **Total** | 86 | 84 | 80 | 87707 |
| **Province** | | | | |
| Western Cape | 86 | 83 | 79 | 11882 |
| Northern Cape | 77 | 74 | 69 | 4307 |
| Free State | 87 | 84 | 81 | 6848 |
| Eastern Cape | 77 | 75 | 72 | 12172 |
| Kwazulu-Natal | 87 | 84 | 81 | 16042 |
| Mpumalanga | 91 | 89 | 86 | 4574 |
| Limpopo | 87 | 84 | 81 | 4998 |
| Gauteng | 91 | 88 | 86 | 22090 |
| North-West | 87 | 84 | 81 | 4794 |
| **Total** | 86 | 84 | 80 | 87707 |

Iterated best responses is used to simulate prices for each scenario in each year between 2011 and 2014. The simulations are run using termination costs as marginal costs, applying termination rates in 2009 for the whole period in the 'no regulation' scenario.

six waves of South African survey data on 134,000 individuals collected between 2009 and 2014. We estimate a discrete-choice model allowing for individual-specific price-responsiveness and preferences for network operators. We find that the price-sensitivity of subscriptions to mobile networks is affected by income and by factors linked to individuals' wealth in South Africa, such as race and language. We use the estimates of the demand parameters and individual price-responsiveness to simulate market outcomes in the absence of a new entrant, Telkom Mobile, which launched mobile services in late 2010, and without Cell C, which launched services in around 2002. We then simulate the effects of eliminating the regulation of mobile termination rates, which are the prices that mobile operators charge one another for incoming calls.

Based on our equilibrium model of demand and supply, we find that the adoption of mobile phones in South Africa would be lower by about two percentage points on average over the period between 2011 and 2014, without the entry of Telkom Mobile and Cell C. Thus, entry led to a relatively small increase in the total number of adopters. On the other hand, the regulation of mobile termination rates had a more significant impact on uptake. Absent regulation, mobile penetration would have been six percentage points lower. The positive effect of entry and regulation on the uptake of mobile services is higher for low-income groups. Without entry, mobile penetration among low-income consumers would have been four percentage points lower, compared to a reduction of two percentage points for high-income earners. Without regulation, mobile penetration among low income consumers would have been eight percentage points lower, compared to four percentage points among high-income consumers.

We also use the model to simulate changes in consumer welfare for different income groups and segments of society. We find that while a 'rising tide lifts all boats', in that all consumers benefit from entry and regulation, high-income consumers benefit more in respect of consumer surplus. This is consistent with our reduced-form analysis, which shows that new entrants target areas that have a higher proportion of richer consumers.

Our paper contributes to the literature by providing an equilibrium-based assessment of the distributional welfare effects of entry in the mobile telecommunications sector. We assess these distributional consequences in circumstances where income-inequality is extremely high. The mobile telecommunications industry is of particular importance in South Africa and other developing economies where there is limited fixed-line infrastructure to make phone calls and access the Internet. A growing dissatisfaction with the performance of the telecommunications industry in South Africa, including high prices and poor Internet infrastructure, resulted in market inquiries into competition being launched by the competition authority in 2017 and by the telecommunications regulator in 2018. Also, in 2017, the South African government put forward a proposition to award significant amounts of future high-demand spectrum to a regulated wholesale open-access network (WOAN) in which existing operators would be shareholders, instead of providing for new market entry or distributing the licences to current market players. This idea has received mixed responses from mobile operators and other stakeholders.

Our analysis is an important contribution to this discussion by demonstrating that the two latest market entrants were relatively ineffective in generating and distributing welfare among South African consumers. Wholesale price regulation had a greater effect on consumer surplus but also benefited higher-income consumers more than low-income consumers. There is an urgent need for solutions on rolling out networks in low-income urban and rural areas to bring more benefits to poor consumers and reverse the distributional welfare effects. The roaming agreements between small and large networks do not seem to be enough. Further wholesale regulation may be necessary.

# 4 Substitution between fixed and mobile data amidst high levels of poverty and inequality

## 4.1 Introduction

Mobile broadband is the main means of connecting to the internet in developing countries, where fixed-line coverage is typically limited or non-existent.[27] As a result, governments in developing countries are seeking means by which mobile broadband penetration might be increased. One such intervention is regulating mobile networks on an 'open access' (shared infrastructure) basis, which is similar to the unbundling of the local loop in respect of fixed lines in many developed countries. For example, in Russia, Mexico and Rwanda, the government forced the separation of wholesale upstream mobile network services and downstream retail services by assigning spectrum to wholesale-only upstream ventures.[28] The government in Kenya considered a similar intervention and the government in South Africa has proposed a wholesale open access mobile network.

These interventions may offer a way to catch up with developed countries in respect of broadband penetration. Moreover, the impact of mobile phones and internet access has attracted a lot of attention among policymakers and researchers. Mobile networks are significantly less costly to deploy and can be used to 'leapfrog' fixed lines for broadband access. For instance, Aker and Mbiti (2010) and Blimpo et al. (2017) discuss the role of mobile phones for economic development in Africa. In another recent paper, Hjort and Poulsen (forthcoming) found a positive impact of broadband on employment and labour productivity in African countries.[29]

However, mobile broadband has physical usage constraints due to the limited capacity of radio frequency spectrum, which is not the case for fixed-line broadband. As a result, mobile broadband typically has usage limits and high prices per unit of usage (per gigabyte) which

[27] We consider fixed lines to be mainly copper or optical fibre connections to homes and businesses. There are a relatively small number of fixed-wireless connections in South Africa, where the end-user device is at a fixed location but the technology may be wireless, such as via satellite or other wireless technology. We consider that mobile broadband is offered in South Africa using EDGE, 3G or 4G connectivity. Most connections over the relevant period were 3G connections.

[28] Regulating open access to mobile networks is not limited to developing countries. For example, in the merger between T-Mobile and Orange in the UK (creating Everything Everywhere, EE), the UK Competition Commission insisted on remedies that forced EE to provide radio-access network sharing with Three UK in order to preserve the latter as an effective competitor.

[29] Additional papers that comment on the impact of mobile phones on economic development include those by Jensen (2007), Muto and Yamano (2009) and Aker (2010).

results in lower usage per connection, while fixed-line broadband has significantly lower prices per unit and higher usage per connection. There is therefore a question as to whether mobile broadband can really replace fixed broadband in developing countries, or whether these two technologies complement each other as appears to be the case in developed economies, where most people rely on mobile and fixed broadband access together.

South Africa is an interesting place to study fixed and mobile substitution, because even though mobile broadband 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 sub-sea optical fibre cables, which were connected to the African continent over the past decade.[30] South Africa therefore lies between developing countries in Africa which have very few fixed-lines and developed countries which have close to universal fixed-line coverage.

In this paper, we analyse fixed and mobile substitution for voice and data services. There are many studies on fixed and mobile substitution of voice services in developed countries. But there are no papers that consider substitution between mobile and fixed broadband access using detailed individual-level data in a developing country setting, where fixed-line infrastructure is underdeveloped and people mainly rely on mobile connections.

This research is useful for a number of reasons. First, the assessment of substitution or complementarity between fixed and mobile networks can support ongoing market inquiries into broadband services launched by regulators. For instance, the competition authority and the telecommunications regulator in South Africa separately launched market inquiries in 2017 and 2018 into the cost of data services. Second, it is useful for understanding the means by which broadband penetration can be increased and thus help bridge the 'digital divide'. The 'digital divide' arises within and between countries where access to technology is higher in developed

[30]Licenses were granted to more than 400 licensees in around 2009, when a court ordered that limited-service licences issued under the previous telecommunications law be converted to full-service licences under the new Electronic Communications Act, no. 36 of 2005. In respect of sub-sea cables, the Seacom cable, which connects the North-East coast of South Africa with countries along the East coast of Africa, India and Europe, became operational in 2009. The East African Submarine Cable System (EASSy) lands in the same area in South Africa and connects with countries along the East cost of Africa, ending with Port Sudan in Sudan. Onward routes are provided via third party cable systems. Services on the cable have 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 West coast of Africa and in Europe.

compared to developing countries and is skewed towards high-income consumers within countries (see, for example, Bulman and Fairlie, 2016). This is an especially important problem in South Africa, where fixed-line broadband is available mainly in formerly Whites-only areas. Furthermore, we are able to capture at the individual level the role of factors that drive broadband penetration, including access to computers and access to the internet at work or school, which have not been emphasized previously. This corroborates survey evidence in South Africa and other countries that identify the high cost or lack of equipment, such as computers, as being a barrier to using the internet at home, rather than the price of subscribing to a service.[31]

We address these questions using survey data of more than 134,000 individuals for the years between 2009 and 2014. For each individual in the sample, we assess whether fixed and mobile data services are substitutes or complements, which depends on observed individual characteristics. We estimate a discrete-choice model where households may choose one or both fixed and mobile voice and data services. A key problem in the assessment of fixed and mobile substitution is separating out correlation of preferences with true complementarity or substitution.[32] We address this by using factors that shift the utility of fixed-line services without shifting the utility derived from mobile. In particular, we use information on consumers having a fixed-line at work or a gaming console (such as an Xbox) which shift the utility of fixed voice and fixed data access respectively but do not shift utility of having a mobile service.

We find that on average mobile and fixed data services are substitutes. But there is also a substantial share of individuals who perceive them as complements. In particular, we find that fixed and mobile broadband access are complements for a greater share of consumers who are employed, have higher incomes or have a computer, or have access to the internet at work or school. Thus, our analysis confirms that in developing economies people with lower incomes substitute mobile broadband for fixed broadband access. But at higher income levels and once consumers acquire a computer, they will derive higher utility from combining both mobile and

[31]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 that do not have internet access at home cite that their reason for this is that the cost of subscriptions is too high. Further evidence corroborating this result is found by Research ICT Africa who find in the 'After Access' survey that the cost of devices is the largest barrier to internet access in South Africa (see report published in 2018 entitled "The State of ICT in South Africa"). For examples of similar results from surveys in the U.S. see Hauge and Prieger (2010).

[32]See, in general, Samuelson (1974) and Berry et al. (2014) for a discussion on the challenges with identifying complementary goods.

fixed broadband access. We conclude that one of the ways of increasing both fixed and mobile broadband penetration is by expanding access to computers and by making internet available at work and educational facilities. In our counterfactual simulations, we show that this is more important than reducing prices of mobile data services by 10% through possible regulatory intervention. Furthermore, since we observe that employed and self-employed individuals derive higher utility from combining fixed and mobile services, having access to both technologies would increase welfare for higher employment levels. This is important since South Africa, like many developing countries in Africa, has very high levels of unemployment (37% using the expanded definition) which leads to high levels of poverty and inequality.

The remainder of the article is organized as follows. Section 4.2 discusses the relevant literature. Section 4.3 discusses the telecommunications sector and demographics in South Africa. Section 4.4 discusses the data used in the estimation. Section 4.5 introduces the econometric framework. Section 4.6 presents the estimation results. Finally, Section 4.7 concludes.

## 4.2 Literature Review

A number of papers consider whether fixed and mobile telecommunications services are substitutes or complements. However, much of the literature is focused on voice services and relies on aggregate country-level data (Ward and Zheng, 2012; Grzybowski, 2014; Briglauer et al., 2011).

There are also papers that analyse consumer-level data in order to assess whether fixed and mobile access (mainly voice) are substitutes. Rodini et al. (2003) evaluate fixed and mobile access substitution using panel data on U.S. households. They use a binary logit model to estimate own- and cross-price elasticities of demand and find that fixed and mobile access (mainly voice) services are substitutes. Ward and Woroch (2010) use panel survey data on U.S. households for the years between 1999 and 2001 to test fixed and mobile substitution in respect of voice services. They use various approaches, including a difference-in-difference analysis, to estimate own- and cross-price elasticities of demand. They find that the two services are substitutes and in a simulation find that universal service had a negligible effect on overall phone penetration (fixed and mobile). Suárez and García-Mariñoso (2013) use panel data on Spanish households for the years between 2004 and 2009 to analyse substitution from fixed to mobile access in a binary logit model. They find that larger households and those with older members are less likely to switch to mobile. The authors also find that the availability of the Internet reduces the likelihood of fixed to mobile substitution, while prices and expenditures have only a small or no impact on the substitution decision.

There are also papers that consider fixed and mobile substitution in respect of internet access services. Cardona et al. (2009) analyse survey data for Austria and find high elasticities of demand for DSL services in areas where cable and mobile broadband are available (and lower elasticities where they are not). Their main finding is that cable and DSL form part of the same market but they could not conclude whether mobile broadband by itself can constrain DSL and cable because it had low penetration in Austria in 2006. Grzybowski et al. (2014) use data on 6,446 households in Slovakia to assess fixed and mobile substitution. They find relatively high elasticities of demand for fixed-line services, which means that the market for broadband services includes mobile services. Part of the reason for this is that, in former Soviet countries in Central and Eastern Europe (CEE), the copper networks were of poor quality. However, none of these studies consider Internet and voice services within the same model. Furthermore, these studies do not allow fixed and mobile to be substitutes or complements.

Another stream of recent literature on telecommunications services allows modelling complementarity or substitution of consumer choices. Liu et al. (2010) use panel data on 2,590 households in the U.S between 2004 and 2006 and develop a discrete-choice model that allows for additional utility from obtaining two services from the same provider, and for inertia in the choice of provider. They find that broadband, cable TV and local phone services are complementary. Moreover, consumers prefer obtaining these services from a single provider and they prefer using the same provider over time. They also find that having an internet connection at work results in a greater probability of having an internet connection at home. This may be due to 'learning effects' where users of high-speed internet at work learn applications for high-speed internet at home. In another paper, Macher et al. (2012) use U.S. household data for the years between 2003 and 2010 in a bivariate probit model to analyse whether fixed and mobile connections are substitutes or complements. Analysing cross-price effects, they conclude that mobile and fixed connections are substitutes rather than complements. Grzybowski and Verboven (2016) use survey data on about 160,000 households, collected between 2005 and 2011 in 27 EU countries, to analyse substitution from fixed-line to mobile voice access. While they find significant fixed-to-mobile substitution, their results show significant heterogeneity between households and EU regions. They find stronger substitution in Central and Eastern European countries, where the quality of fixed lines is poorer. They also find that the decline in fixed connections has been slowed by complementarity with broadband internet.

Our approach is similar to the latter paper and follows Gentzkow (2007), where we permit heterogeneity in substitution across households. This allows us to conclude whether fixed and mobile voice and data connections are substitutes, complements or independent from each other among different groups of consumers.

### 4.3 Industry

In South Africa over the period between 2009 and 2014, there was one partial-coverage fixed-line operator (Telkom) and two full-coverage mobile operator networks (MTN and Vodacom).[33] There were also two smaller mobile networks, Telkom Mobile (a division of the fixed-line incumbent) and Cell C, which used a combination of their own networks and national roaming on the MTN and Vodacom networks. All mobile operators' services are thus available throughout South Africa. At the same time, the fixed-line network is available mainly in urban areas that were reserved for Whites only during apartheid, which came to an end in 1994. Fixed lines are also available in business areas and in certain areas formerly reserved for Black, Coloured and Indian people where Telkom rolled them out to meet universal service obligations which were imposed on it in the late 1990s. Approximately 5.5 million landlines were rolled out to households in South Africa until 2001 (out of approximately 15 million households in total). In around 2001, the fixed-line incumbent began disconnecting households for non-payment. At that time pre-paid mobile voice services were growing as an alternative to traditional fixed line voice services, at least for low-income consumers (see Hodge, 2005).

Vodacom and MTN began rolling out their Global System for Mobile (GSM) networks in the mid-1990s. Cell C entered the market towards the end of 2001, while Telkom Mobile entered towards the end of 2010. Over the period studied, almost the entire population was covered by 2G or 2.5G (EDGE) internet access by MTN and Vodacom, while Cell C and Telkom Mobile roamed

[33]There were certain other fixed-line networks, however they served largely businesses or small gated communities.

on these networks.[34] But the quality of the smaller networks was lower because customers could lose connectivity when handed over to a roaming partner. MTN and Vodacom covered around 50% of the population with 3G services in 2009 and around 90% by 2014 and the roll-out of 4G began in 2013 (see Figure 10).

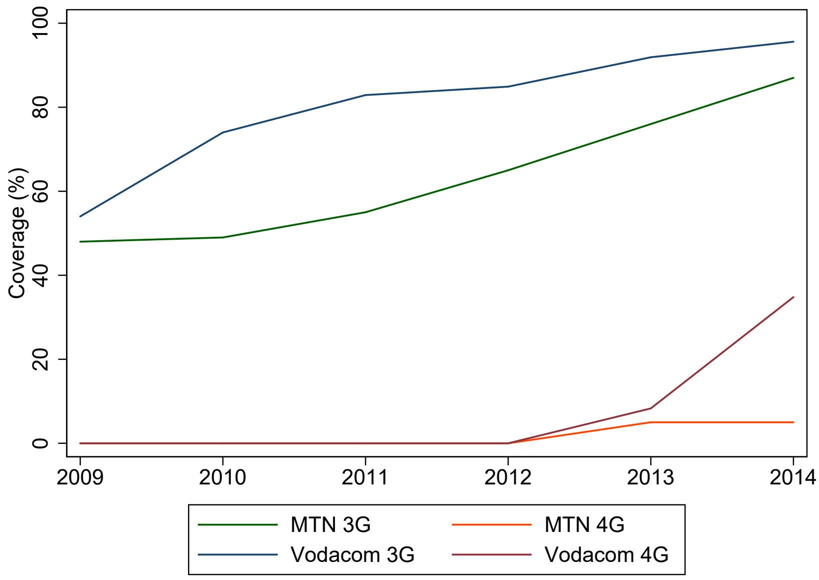



**Figure 10: 3G and 4G coverage in South Africa, 2009-2014 (%)**

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.

According to a survey by the official statistics agency in South Africa in 2017, approximately 60% of households report having at least one member that can connect to the internet, typically via their mobile phone. However, in the same survey, only a small proportion of households reported having an internet connection at home (around 10%), which implies that mobile broadband is used by individuals but not the entire household.[35] This low level of internet penetration at homes reflects the persistence of apartheid policies which excluded the vast majority of the population from basic services such as fixed-line telecommunications.

The lack of connectivity at homes may have led to limited usage of the internet. Almost 40% of consumers that report having an internet connection had not accessed the internet yesterday but rather accessed it 7 days, 4 weeks or 12 months ago.[36] This may be because connectivity

[34]EDGE meets the standard for 3G but is often referred to as 2.5G.
[35]Source: Statistics South Africa, 2017. "General Household Survey", Statistical Release P0318.
[36]Source: Respondents to the All Media Products Survey (2009-2014), used in this paper to analyse fixed and mobile substitution.

via one household member's smartphone or dongle disappears when that member leaves the house. Moreover, mobile networks have capacity constraints related to available spectrum and thus implement maximum usage caps. This suggests that fixed-line broadband may be needed for households to provide all members with unlimited always-on connectivity.

## 4.4 Data

### 4.4.1 Survey data and demographics

We use six waves of the All Media Products Survey (AMPS) in the estimation. AMPS is a survey of approximately 25,000 consumers each year between 2009 and 2014. An exception is 2013, when data on only half that number is available.[37] The total number of observations is almost 138,000 observations, before data processing. This dataset contains information on consumer choices of a range of products and services as well as on personal and household characteristics. The survey samples a greater proportion of higher-income consumers in urban areas than a nationally representatitive sample would.[38] Nonetheless, the survey includes large sample sizes across race, income and other demographic groups (see Table 17).

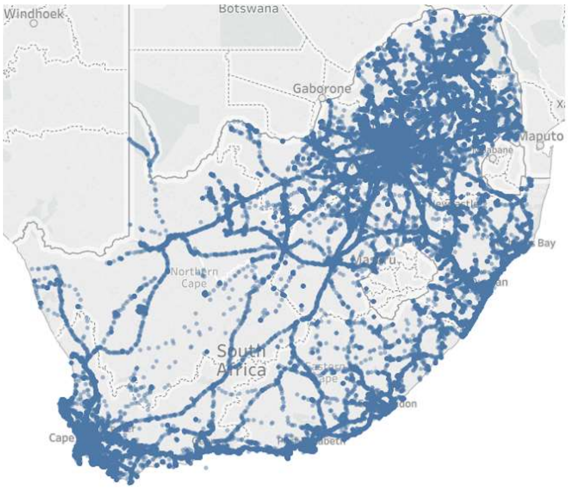
We use the survey to model choices of fixed and mobile voice and data services. To do this we need to account for the geographic coverage of the networks to define what choices consumers have. As discussed in Section 4.3, over the period between 2009 and 2014, most of the population in South Africa was covered by mobile broadband services. While a map of cellphone towers shows coverage gaps, these are typically in sparsely populated areas (see Figure 11a).

We do not have information on coverage by the fixed network and we use the survey data to define fixed-coverage areas. A map of Telkom's fixed-line broadband exchanges shows that they are concentrated in cities and towns. There are also a number of exchanges scattered in rural areas, which were often rolled out to serve White farmers during apartheid (see Figure 11b).

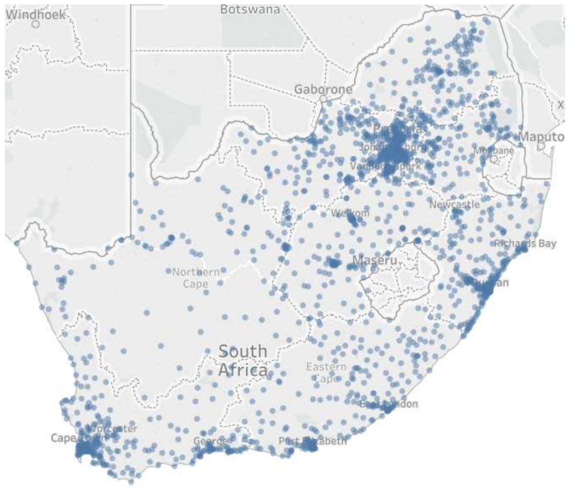
During apartheid, the population was segregated according to racial groups, which were Black, White, Indian and Coloured. These patterns of segregation have persisted in the post-

[37]The AMPS survey is a rolling six-month survey of approximately 12,500 consumers in each period. The committee responsible for the survey omitted several questions used in our model in the July-December 2013 period and this made the observations unusable.

[38]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. The data was made available to us by DataFirst at the University of Cape Town.




**(a) Approximate locations of cell masts (2017)**




**(b) Telkom fixed-line local exchanges (2014)**

**Figure 11: Maps indicating cell sites and fixed-line local exchanges**

Figure (11b) shows locations of 1,864 local exchanges identified by broadbandstats.co.za in 2014. Figure (11a) shows estimates of positions of high sites and masts 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 18) uses number of masts and high sites reported by the mobile operators in annual reports and other public sources.

Apartheid era, and we rely on this to define fixed-line coverage over the period we study here (2009-2014). In particular, fixed-lines have largely not been rolled out or have been disconnected outside of Whites-only areas due to the theft of copper cables in rural areas and non-payment of postpaid services. As a result of discriminatory policies in this period, White people have significantly higher incomes compared to other racial groups. Indian people were discriminated against during apartheid but benefited from having more access to public resources and from living in urban areas, while many Black and Coloured people live in rural areas with substantially lower funding for education and healthcare. Indian people therefore have lower incomes than White people though both groups have higher incomes than Black and Coloured people. Many Black people were forced during apartheid to live in rural 'homelands' and had to carry pass books to be allowed into urban areas, known as the 'dompas'. These rural homelands were closely associated with race and language groups, and provinces that integrated homelands continue to be characterised by this.

We use this demographic information in order to determine whether a household has fixed-line coverage. First, for the reasons stated above, we consider that fixed lines are available to all

White households, including in rural areas. Second, we consider that fixed lines are only available to Black, Coloured and Indian households where the following is reported on the dwelling: (i) has a flush toilet inside or outside, (ii) is a house or flat (and not a hut or a shack), (iii) has a water connection and (iv) indoor plumbing (a built-in kitchen sink) and (v) has an electricity connection (see Figure 12). Furthermore, we consider that Black and Coloured households in rural areas (i.e. living on farms etc.) do not have fixed-line coverage. These assumptions imply that two-thirds of individuals in the AMPS dataset has fixed-line coverage. This number appears to be higher than the true population coverage of the fixed-line network, which as discussed above at its height covered approximately 5.5 million out of 15 million households in South Africa. But we observe that the AMPS survey includes a greater proportion of people living in urban areas who also tend to have higher incomes.

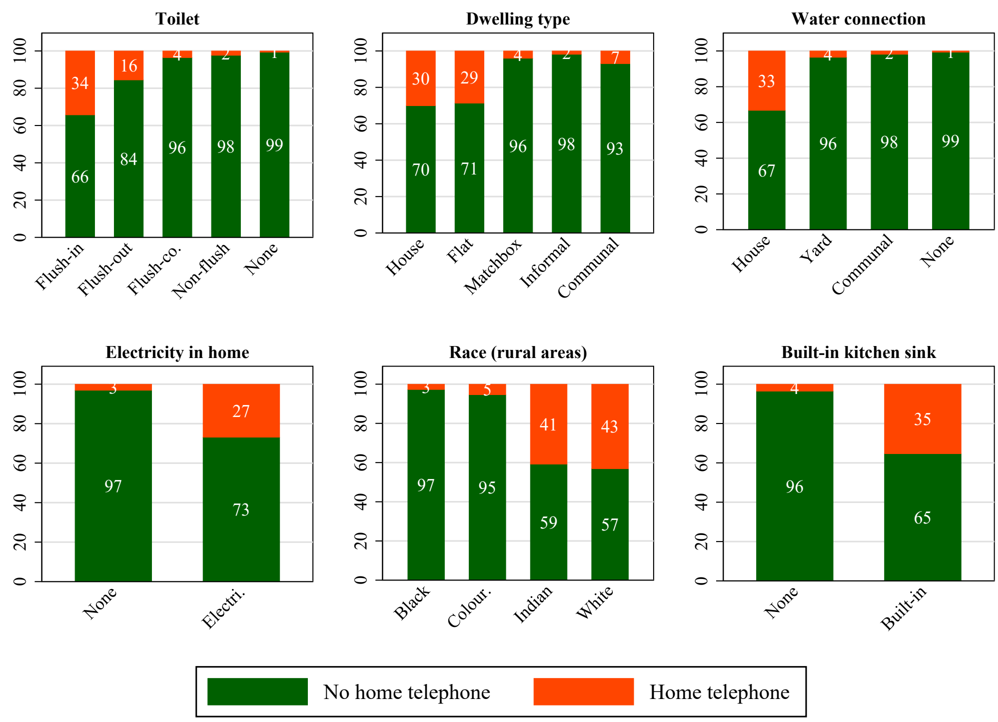



**Figure 12: Identifying areas with no fixed-line coverage (%)**

AMPS survey respondents, pooled, 2009-2014 (N=137,321).

We dropped 1,951 observations where consumers responded having a telephone at home while according to our assumptions they live in areas with no fixed-line coverage.[39] We also

[39]We carried out robustness checks to see whether alternative means of developing a proxy for fixed-line coverage

dropped 612 observations where consumers reported having a mobile internet connection and at the same time declared not having a mobile network operator. In our model, households with no fixed-line coverage have a choice set limited to mobile services. They can choose between between no mobile, mobile voice only or mobile voice and data provided by one of the network operators. All users within a fixed-coverage area are then also given the option to choose between no fixed services, fixed voice and fixed voice & data services (see Table 15 and Table 16).

**Table 15: Network operator choices made by consumers in 2014**

| | **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.

The usage of fixed or mobile connections in South Africa varies significantly depending on demographic characteristics (see Table 17). A large proportion of consumers that have computers also have a fixed line or mobile service (48% of consumers that have a computer also have a fixed line, whereas only 14% of consumers that do not have a computer have a fixed line). At the same time, almost all consumers in our sample that have both fixed and mobile data connections also have a computer. This is in line with the experience in other countries: the positive relationship between access to the internet at home and having a computer can also be observed across countries (see Figure 13). The lack of a computer has also previously been reported as a barrier

would lead to a different outcome. First, we removed the assumption that all White households have fixed-line coverage. This resulted in 2,182 households having a telephone at home while not having fixed line coverage, which is not very different to our baseline assumption. Next, we reinstated the coverage assumption in respect of White households and removed the 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.

Table 16: **Fixed and mobile choices made by consumers 2009-2014**

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

to the adoption of broadband services (see, for example, Hauge and Prieger, 2010).

Similarly, a larger proportion of individuals that have an internet connection at work or school choose fixed and mobile data compared to those that do not. A similar result is found by Liu et al. (2010).

As can be expected, the usage of fixed and mobile services increases with income which in South Africa is strongly correlated with race. The proportion of consumers that use a mobile service does not vary among racial groups but the proportion using fixed lines does. While 49% of White consumers have a fixed connection, only 8% of Black consumers do. Fixed and mobile choices among different language groups roughly follow the corresponding race group. While choices of mobile are roughly similar among language groups, a significantly larger proportion of English and Afrikaans-speakers (who are predominantly White, Coloured and Indian) have fixed-line services. In addition, language and race overlap with geographic regions (provinces) in South Africa.[40]

[40]There are eleven official languages in South Africa. The languages spoken most often are Zulu, Xhosa, Afrikaans, English, Northern Sotho (Sesotho sa Leboa or Sepedi), Setswana and Sesotho. The languages spoken by relatively smaller minorities are Xitsonga, siSwati, Tshivenda and isiNdebele. The main language in the KwaZulu-Natal province, the most populous province in South Africa, is Zulu. Xhosa-speakers mainly live in the Eastern Cape. Afrikaans and English are spoken mainly in towns and cities including in Gauteng province, and Afrikaans is also spoken in the Western Cape and Northern Cape provinces, including in rural areas particularly among Coloured people. A significant proportion of Sepedi and Tshivenda-speakers live in Limpopo, while Sesotho-speakers largely live in the Free State (a province bordering Lesotho). Setswana speakers largely live in the neighbouring North-West province. Siswati speakers and a significant proportion of isiNdebele speakers live in Mpumalanga province which borders eSwatini (Swaziland). A significant proportion of Xitsonga-speakers

**Table 17: Consumer choices of fixed and mobile services, by demographic variables (2009-2014)**

| | Fixed | Mobile | F&M voice | F&M voice & data | N |
|---|---|---|---|---|---|
| No computer | 14 | 79 | 9 | 0 | 90,540 |
| Computer | 48 | 94 | 34 | 11 | 44,202 |
| No Internet at work/school | 23 | 82 | 16 | 3 | 121,203 |
| Internet at work/school | 40 | 98 | 29 | 10 | 13,539 |
| Income <3,000 | 8 | 69 | 4 | 1 | 30,871 |
| Income 3-7,999 | 16 | 82 | 11 | 1 | 37,743 |
| Income 8-15,999 | 30 | 89 | 22 | 3 | 33,081 |
| Income >15,999 | 46 | 95 | 33 | 10 | 33,047 |
| Black | 8 | 83 | 5 | 1 | 69,334 |
| Coloured | 27 | 75 | 19 | 3 | 19,398 |
| Indian | 55 | 83 | 37 | 6 | 8,981 |
| White | 49 | 89 | 35 | 8 | 37,029 |
| Afrikaans | 32 | 82 | 23 | 4 | 36,748 |
| English | 54 | 88 | 38 | 9 | 31,487 |
| Zulu, Swazi, Ndebele | 8 | 85 | 6 | 1 | 20,807 |
| Xhosa | 7 | 78 | 5 | 1 | 15,558 |
| Sth., Tsw., Tsn., Ven., Oth. | 7 | 84 | 5 | 1 | 30,142 |
| Age < 26 years | 17 | 85 | 12 | 4 | 39,098 |
| Age 26-50 years | 20 | 89 | 14 | 4 | 59,851 |
| Age 51-65 years | 36 | 81 | 26 | 4 | 23,117 |
| Age > 65 years | 54 | 65 | 33 | 2 | 12,676 |
| No or some High School | 16 | 73 | 10 | 1 | 61,467 |
| High School or more | 33 | 93 | 24 | 6 | 73,275 |
| Unemployed | 24 | 79 | 16 | 2 | 80,866 |
| Employed | 26 | 92 | 20 | 5 | 53,876 |
| Not self-employed | 24 | 83 | 17 | 3 | 121,874 |
| Self-employed | 37 | 93 | 27 | 9 | 12,868 |
| Rural | 7 | 76 | 6 | 1 | 21,031 |
| Towns | 32 | 87 | 23 | 5 | 67,915 |
| Cities | 22 | 83 | 16 | 3 | 45,796 |
| Home owned | 28 | 83 | 20 | 4 | 101,812 |
| Home rented | 16 | 86 | 11 | 3 | 32,930 |
| Male | 24 | 83 | 17 | 4 | 67,171 |
| Female | 26 | 85 | 18 | 3 | 67,571 |
| Household size <=2 | 30 | 83 | 21 | 4 | 45,520 |
| Household size > 2 | 22 | 84 | 16 | 4 | 89,222 |
| 1 earner in household | 18 | 82 | 12 | 2 | 62,430 |
| 2+ earners in household | 31 | 85 | 22 | 5 | 72,312 |
| <=1 cell in household | 19 | 59 | 9 | 1 | 35,311 |
| >1 cellphone in household | 27 | 92 | 21 | 5 | 99,431 |
| No work telephone | 23 | 82 | 16 | 3 | 120,465 |
| Work telephone | 43 | 95 | 33 | 8 | 14,277 |
| No console | 22 | 82 | 15 | 2 | 117,234 |
| Console (e.g. Xbox) | 47 | 95 | 32 | 13 | 17,508 |
| **Total** | 25 | 84 | 18 | 4 | 134,742 |

The numbers reported are proportions of consumers from a particular demographic having made the choice indicated in the column title, except for the last column which shows the absolute number of consumers in that demographic. Note that proportions are not adjusted for fixed-line coverage.

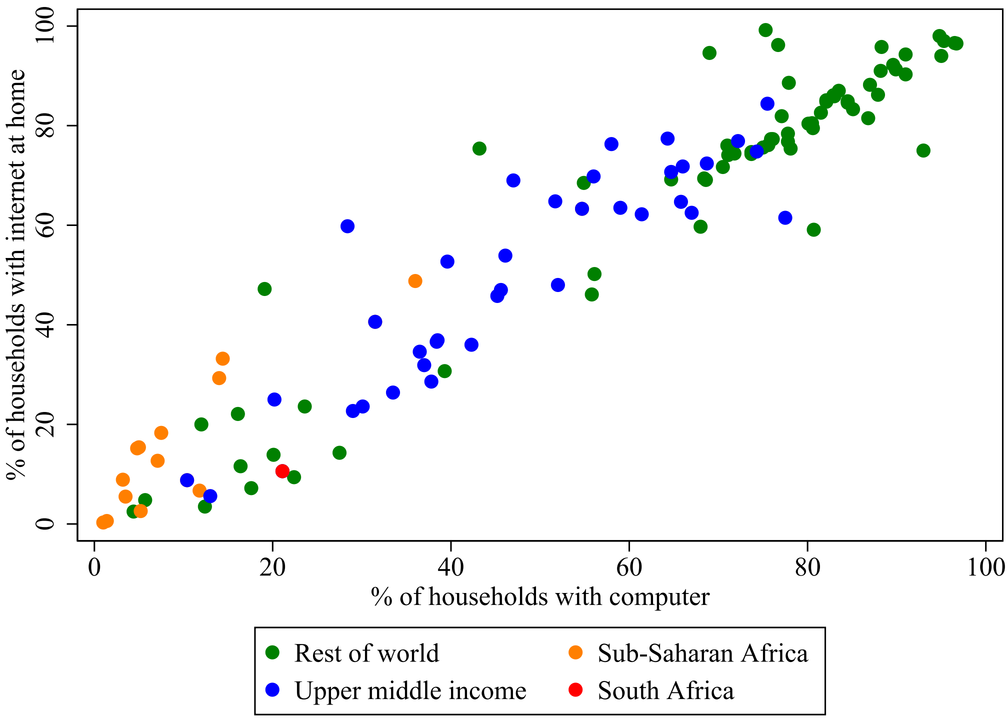



**Figure 13: Relationship between internet access at home and having a computer, 2012-2016)**

Figure produced using data from the International Telecommunications Union (ITU). Note that for South Africa the ITU estimate of internet access at home 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.

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 4.6.

### 4.4.2 Prices

Prices used in our model were obtained from Research ICT Africa (2010-2015) and Tarifica.[41] In addition, we completed the database using an online archive service, the Internet Archive. Prices of voice services were matched to consumers by payment method (pre-paid or post-paid)

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also live in Mpumalanga and neighbouring Limpopo. Since the Zulu, siSwati and isiNdebele languages are linked linguistically and geographically, we group these languages together as 'Zulu+'. Sepedi, Setswana, Sesotho, Xitsonga and Tshivenda are largely spoken in the Northern parts of South Africa, and we group these languages as 'Sesotho+'.

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

and estimated usage of voice minutes based on cellphone spend. Prices of mobile broadband were assigned based on declared intensity of internet usage.

First, we grouped mobile consumers as pre-paid or post-paid users based on the type of contract they have.[42] In respect of voice services, all pre-paid consumers belong to one segment. Post-paid consumers were divided into three groups: low, medium and high users, according to their declared monthly cellphone spend. Low-usage consumers are assumed to have monthly bills in the range R1-150 per month, medium-usage consumers in the range R151-500 per month and high-usage consumers above R500 per month.[43]

Next, we computed average prices per calling minute for each market segment. We assumed different monthly usage of minutes for each segment: 30 minutes for pre-paid (1 minute per day), 180 minutes for low-usage post-paid (6 per day), 540 minutes for medium-usage (18 per day) and 1,080 minutes for high-usage consumers (36 per day).[44] In South Africa, prices differ depending on whether calls are terminated on the same network (on-net), other mobile networks (off-net) or on the fixed network. For pre-paid and post-paid consumers we assume the same distribution pattern of calls where 10% of minutes are terminated on fixed lines and the rest on mobile networks. Calls terminated on mobile networks are distributed according to mobile operator market shares. We also assume that 50% of calls are made in 'peak' times and the balance in 'off-peak' times, for which there are different prices for some tariffs.[45]

[42]In South Africa, most subscribers are on prepaid plans and are typically unable to choose between prepaid and postpaid because they do not meet the income and employment requirements for a postpaid contract. This is a result of low levels of employment and participation in the labour force. According to the "Quarterly Labour Force Survey" undertaken by Statistics South Africa (publication P0211), the employed population divided by the number of adults in South Africa (aged 15-65 years), i.e. the 'labour absorption rate', varied between 41% and 46% over the period between 2009 and 2014. The unemployment rate varied between 22% and 26% using the official definition (active job seekers) while the expanded definition (i.e. including discouraged work seekers) varied between 30% and 36%.

[43]The South African currency is highly volatile but as of December 2018 one US dollar was approximately 14.6 Rands. Classifying consumers into high, medium and low usage groups is a standard approach to segmenting telecommunications subscribers. The spending bands were selected to broadly reflect regular intervals and available mobile packages, and so as to ensure a large number of observations would fall within each category. Approximately 25% of postpaid customers fall within the first group, around 53% fall within the second category and the remaining 22% fall within the highest spend group. The second category has a greater proportion since almost 25% of postpaid customers spend between R271-R500 per month. Since there are many more packages advertised in the R151-R500 spend level than above R500, it made more sense to allocate the R271-R500 category to the medium-spend group.

[44]These usage categories are similar to the OECD mobile voice call baskets cited below, of 30, 100, 300 and 900 calls per month. The groups are also not far from minutes of use reported by Vodacom in its annual reports between 2009 and 2014, for example, for prepaid and postpaid customers. Prepaid customers on the Vodacom network used between 52 minutes and 116 minutes per month on average, depending on the year, while postpaid consumers used between 182 and 240 minutes per month.

[45]This is in line with the OECD usage baskets mentioned above, which assume that 46% of calls are made during the day, 27% are made during the evening and 27% over the weekend. In South Africa, weekend and evening calls

This distribution pattern of phone calls is used to compute the average per minute price for all pre-paid tariffs. We then selected the lowest tariff for each operator in a given year. We assume that pre-paid consumers observe prices generated in this way when choosing tariffs from different operators. We compute average prices per minute observed by post-paid low, medium and high voice usage consumers in a similar way.

In respect of mobile data, the price is determined by the cost of bolt-on bundles, which were typically purchased in addition to basic tariff plans. The operators did not differentiate between prepaid and post-paid bolt-on prices over the period between 2009 and 2014. We classify consumers into low, medium and high data-usage categories based on their declaration of internet use in the survey. Low mobile data users reported being connected to the internet via mobile. Medium users declared using mobile internet for instant messaging and email. High users declared using mobile broadband for photos and video (in addition to instant messaging and email).

Similarly, data bundles offered by mobile operators were categorized depending on customer segment as low, medium and high. If there was more than one tariff plan available in the segment, we used the lowest available price per gigabyte. Mobile voice and data customers could belong to different voice and data profiles and prices were assigned accordingly. For example, a high usage postpaid customer on the MTN network in 2014 paid R1.02 per minute for a voice call assuming usage of 1,080 minutes as described above, and R79.80 per gigabyte for 5 GB of mobile data.

Fixed-line broadband services were typically bundled with voice services which means there is no 'naked ADSL' option. In most years, fixed-line broadband was offered for three usage profiles: low, medium and high and we used these profiles to group fixed-broadband users. Low fixed-data users reported being connected to the internet. Medium users reported accessing the internet for services such as email, banking and news. High users in addition reported accessing the internet for television and gaming. There is a subscription price for voice only, which includes an allowance of voice minutes, and there are prices for bundles of voice and data. Where there was more than one fixed tariff available, we selected the lowest-price alternative. For example, a high-usage fixed data customer would pay R904 per month and receive 40GB of data over

are grouped together under the 'off-peak' period. Source: OECD, 2017, "Revised OECD Telecommunications Price Baskets".

a 10 megabit per second line and unlimited voice calling minutes to other fixed lines.[46] We tested our results against different usage specifications and our estimates of price coefficients are comparable.

### 4.5 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 ($f = f_v$) or combined fixed voice and data services ($f = f_d$). Thus, with respect to fixed broadband, there are three choice alternatives $f \in F = \{0, f_v, f_d\}$, where $f = 0$ refers to the choice of no fixed services at all.

A consumer can subscribe to mobile operator $k$ and choose stand-alone voice services ($m = m_{vk}$) or combined voice and mobile broadband services ($m = m_{dk}$). With respect to mobile services, in 2009 and 2010 there are three mobile networks and seven choice alternatives $m \in M = \{0, m_{v1}, m_{d1}, m_{v2}, m_{d2}, m_{v3}, m_{d3}\}$, where $m = 0$ refers to the choice of no mobile services at all. Between 2011 and 2014, there were four mobile networks and nine choice alternatives including $\{m_{v4}, m_{d4}\}$. Therefore, in 2009 and 2010 there are $7 \times 3 = 21$ choice alternatives in areas that have fixed line coverage and $7 \times 1 = 7$ in areas that do not. Between 2011 and 2014, there are $9 \times 3 = 27$ choice alternatives in areas that have fixed-line coverage and $9 \times 1 = 9$ choices outside of such areas.

Table 15 shows the number of consumers who opt for different choice alternatives in 2014. Table 16 shows how the number of users of fixed and mobile services changes over time.

Individual $i$'s stand-alone utility from a connection to fixed network alternative $f \in F$ is:

$$V_{if} = x_i \beta_f + \alpha_f p_{if},$$

where $p_{if}$ refers to the monthly subscription charge for having voice services only or voice

[46] Uncapped data plans became available from the fixed-line incumbent (Telkom) towards the end of the period analysed and were very expensive relative to capped plans.

combined with broadband access and $x_i$ is a vector of individual characteristics influencing the utility of the fixed service.

As discussed in Section 4.4, we define three different usage profiles. Each consumer that has fixed-line coverage is assigned to one broadband usage profile (low, medium or high) and observes two prices (in addition to no service at zero cost): one for the lowest-cost monthly package of voice and another for voice and data.

The stand-alone utility from a connection to mobile operator, denoted $k$, is:

$$V_{im_k} = x_i\beta_m + \alpha_{m_v} p_{im_{vk}} + \alpha_{m_d} p_{im_{dk}},$$

where $p_{im_{vk}}$ and $p_{im_{dk}}$ are the prices paid by individual $i$ for mobile voice and broadband services from operator $k$, and $x_i$ is the vector of household characteristics influencing the utility of mobile services.

As discussed in section 4.4, we define different usage profiles for mobile voice and data services. Each consumer is assigned to one profile and observes different voice and data prices. The prices used in the estimation are voice call prices per minute and prices for one gigabyte of data.

The prices for mobile and fixed-line connections may be endogenous. This is partly mitigated by the inclusion of a rich set of consumer characteristics $x_i$ (see Table 17), which include: demographics (such as income, race, age, gender, education and whether the home is owned or rented); employment status, including whether self-employed or not; and geographic information (such as living in a city, town or rural area). In the estimation, we also address the problem of endogeneity using the control function approach proposed by Petrin and Train (2010).

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

$$\begin{aligned}
u_{ir} &= \varepsilon_{ir} && \text{if } f = 0 \text{ and } m = 0 \\
u_{ir} &= V_{if} + \varepsilon_{ir} && \text{if } f \neq 0 \text{ and } m = 0 \\
u_{ir} &= V_{im} + \varepsilon_{ir} && \text{if } f = 0 \text{ and } m \neq 0 \\
u_{ir} &= V_{if} + V_{im} + \Gamma_{ir} + \varepsilon_{ir} && \text{if } f \neq 0 \text{ and } m \neq 0
\end{aligned}$$

The term $\Gamma_{ir}$ 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, $V_{if}$, and mobile services, $V_{im}$.

For the 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 $\Gamma_{ir} = 0$.[47]

We estimate one value of gamma for a bundle which combines voice services on the fixed-line network with voice services on any mobile network, denoted $\Gamma_{iv}$.[48] The second value of gamma, denoted $\Gamma_{id}$ is estimated for a bundle which combines fixed and mobile broadband services, which by default comes with voice services. Thus, the second gamma is estimated for a subset of users of voice services, as shown on Table 15.

The substitution (complementarity) coefficients, $\Gamma_{ir}$, may depend on consumer characteristics $x_i$. We define $\Gamma_{ir} = \Gamma_r + x_i\gamma_{ir}$, where $\Gamma_r$ is the stand-alone value common to all individuals, and $x_i\gamma_{ir}$ represents multiplication of vectors which accounts for individual-level variation in complementarity or substitution. The heterogeneity depends on the same individual characteristics which determine utilities of fixed and mobile services.

A key problem in identifying $\Gamma_{ir}$ is separating the correlation of preferences from true complementarity or substitutability. For example, when we observe consumers buying two services we may simply be observing correlation in preferences rather than complementarity. In order to remedy this, Gentzkow (2007) proposed using variables that shift demand for one service but not the other. We employ one demand-shifter for fixed-voice services and another for fixed-data services. The fixed-voice shifter is having a telephone at work, and the fixed-data shifter is having a gaming console. First, having a fixed-line telephone at work means that members of the household have a cheap means of contacting the individual (fixed to fixed calls are often free or are very cheap in South Africa), thus shifting the utility of having a fixed line at home but without affecting the utility from having a mobile. Second, gamers require very low-latency connections, which were only possible using fixed-line broadband connections. Thus, having a

[47] At the time of our analysis there were no significant fixed and mobile bundles on the market, and so our estimates are not driven by bundled discounts or other contractual benefits. Telkom Mobile offered fixed and mobile bundles to some extent, but it was by far the smallest mobile operator with a share of 1% or less in the AMPS sample over the period analysed. Thus, the likely effect of these bundled discounts is negligible.

[48] We do not separately estimate gammas for voice on one technology and voice and data on the other, since we are mainly interested in fixed and mobile substitution in respect of voice services overall. We therefore estimate a single gamma for voice services.

gaming console shifts out the utility for fixed-line broadband without affecting the utility derived from mobile data services. We denote the shifter for fixed voice as $z_i$ and for fixed data as $w_i$.

More specifically, the utility from each of the nine bundles is specified as follows:

$$
\begin{aligned}
u_{i0} &= \varepsilon_{i0} \\
u_{ifv} &= x_i\beta_f + z_i\beta_{fv} + \alpha_f p_{if} + \varepsilon_{ifv} \\
u_{ifd} &= x_i\beta_f + z_i\beta_{fv} + w_i\beta_{fd} + \alpha_f p_{if} + \varepsilon_{ifd} \\
u_{imv} &= x_i\beta_m + \alpha_{mv} p_{im_{vk}} + \varepsilon_{imv} \\
u_{imd} &= x_i\beta_m + \alpha_{mv} p_{im_{vk}} + \alpha_{md} p_{im_{dk}} + \varepsilon_{imd} \\
u_{ifv+mv} &= x_i(\beta_f + \beta_m + \gamma_v) + z_i\beta_{fv} + \alpha_f p_{if} + \alpha_{mv} p_{im_{vk}} + \varepsilon_{ifv+mv} \\
u_{ifv+md} &= x_i(\beta_f + \beta_m + \gamma_v) + z_i\beta_{fv} + \alpha_f p_{if} + \alpha_{mv} p_{im_{vk}} + \alpha_{md} p_{im_{dk}} + \varepsilon_{ifv+md} \\
u_{ifd+mv} &= x_i(\beta_f + \beta_m + \gamma_v) + z_i\beta_{fv} + w_i\beta_{fd} + \alpha_f p_{if} + \alpha_{mv} p_{im_{vk}} + \varepsilon_{ifd+mv} \\
u_{ifd+md} &= x_i(\beta_f + \beta_m + \gamma_d) + z_i\beta_{fv} + w_i\beta_{fd} + \alpha_f p_{if} + \alpha_{mv} p_{im_{vk}} + \alpha_{md} p_{im_{dk}} + \varepsilon_{ifd+md}
\end{aligned}
$$

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

$$s_{ir} = \frac{\exp(V_{ir})}{1 + \sum_r \exp(V_{ir})} \tag{14}$$

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

The choice probabilities form the basis of the likelihood function applied to the data. The summations in the numerator of (14) are modified to adjust for the limited geographic coverage of fixed broadband and different numbers of mobile operators, depending on the year, discussed in Section 4.4. Defining $y_{ir} = 1$ if individual $i$ selects voice bundle $r$, and $y_{ir} = 0$ otherwise, the log likelihood function can be written as:

$$\mathcal{L}(\theta) = \sum_{i}^{N} \sum_{r} y_{ir} \log s_{ir}(\theta) . \tag{15}$$

where $\theta$ is the vector of all parameters to be estimated. The maximum likelihood estimator is the value of the parameter vector $\theta$ that maximizes (15).

## 4.6 Empirical Results

### 4.6.1 Estimation results

First, we estimate control functions for voice services (Table 18) and data services (Table 19) in order to control for endogeneity between prices and choices. In both cases, we use measures of

**Table 18: Control function estimation results - voice services**

| | | **Coeff.** | **(STD)** |
|---|---|---|---|
| Termination cost | | 1.30*** | (0.16) |
| MTN | | 0.80*** | (0.16) |
| Telkom | | 0.36* | (0.18) |
| Vodacom | | 0.50** | (0.16) |
| Prepaid | | 0.68*** | (0.16) |
| Postpaid* | Medium | 0.18 | (0.16) |
| | High | 0.44** | (0.16) |
| MTN* | Prepaid | -0.28 | (0.22) |
| | Postpaid medium | -0.21 | (0.22) |
| | Postpaid high | -0.22 | (0.22) |
| Telkom* | Prepaid | -0.42+ | (0.25) |
| | Postpaid medium | -0.21 | (0.25) |
| | Postpaid high | -0.27 | (0.25) |
| Vodacom* | Prepaid | -0.07 | (0.22) |
| | Postpaid medium | -0.14 | (0.22) |
| | Postpaid high | -0.19 | (0.22) |
| Constant | | -0.02 | (0.14) |
| Number of obs | 88 | | |
| R-squared | 0.68 | | |

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

costs as instruments, and we include dummy variables for the operators and market segments. In the case of voice services, we use the costs of call termination.[49] In respect of mobile data

[49] We computed the termination costs for each mobile operator as follows. First, we consider that 90% of calls are made to other mobile networks (the other 10% are to fixed networks) and that calls to other mobile networks are distributed according to market shares. We further consider that 50% of calls are made during peak hours and 50% are made off-peak, since termination rates were different for these two time slots. Using this information, we computed an average termination cost per minute paid by each mobile operator in each year.

Table 19: **Control function estimation results - data services**

| | **Coeff.** | **(STD)** |
|---|---|---|
| Sites | 66.41+ | (37.59) |
| Medium usage | -228.26*** | (48.35) |
| High usage | -418.60*** | (48.35) |
| MTN | -514.71+ | (270.31) |
| Telkom | 104.82 | (91.15) |
| Vodacom | -520.09* | (245.65) |
| 2010 | -168.93* | (76.43) |
| 2011 | -353.62*** | (82.04) |
| 2012 | -452.82*** | (97.01) |
| 2013 | -692.34*** | (120.93) |
| 2014 | -731.32*** | (134.55) |
| Constant | 828.81*** | (99.58) |
| Number of obs | 66 | |
| R-squared | 0.75 | |

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

services, we use the number of sites.[50] Termination rates are regulated in South Africa. The number of sites does not respond to short-term demand shocks and is at least partly set in terms of coverage requirements by the regulator. This is in the spirit of Czernich et al. (2011), who use copper network infrastructure as an instrument for broadband penetration. Termination costs and sites are positively related to voice and data prices in the respective control function regressions. In respect of voice, this is consistent with findings in previous papers, including Genakos and Valletti (2015). That there is a positive relationship between sites and data prices is also reasonable, since the average cost (and therefore price) per gigabyte rises with the greater number of sites rolled out. The R-squares are relatively high at 0.68 for the voice and 0.75 for the data regression.

The results from the multinomial logit regression are shown on Table 20.

In column (1), the following results are shown: (i) three price coefficients; (ii) a dummy variable for having a fixed connection from Telkom; (iii) fixed broadband speed associated with a tariff plan and controls for quality; (iv) dummy variables for four mobile operators which are estimated relative to not having a mobile phone; (v) a dummy variable for mobile data access on top of voice; (vi) residuals from control function regressions for voice and data; (vii) the shifters for fixed voice (having a telephone at work) and fixed data (having a gaming console).

All three price coefficients, for mobile voice, mobile data and fixed voice and data have the

[50]We collected information on the number of sites from operator annual reports and other public sources of information, such as news reports.

## Table 20: Estimation results

| **Main effects** | (1) Coeff. (SE) | **Interactions** | (2) Fixed Coeff. (SE) | (3) Mobile Coeff. (SE) | (4) $\Gamma_{FMV}$ Coeff. (SE) | (5) $\Gamma_{FMVD}$ Coeff. (SE) |
|---|---|---|---|---|---|---|
| Price - mobile voice | -0.777*** | $\Gamma$ (average) | | | 0.603** | -1.400*** |
| | (0.024) | | | | (0.256) | (0.191) |
| Price - mobile data | -0.009*** | Computer | 0.785*** | 0.473*** | | 1.461*** |
| | (0.000) | | (0.019) | (0.030) | | (0.071) |
| Price - fixed | -0.004*** | I'net work/sch. | 0.189*** | 0.662*** | | 0.432*** |
| | (0.000) | | (0.026) | (0.061) | | (0.048) |
| Fixed line | -2.667*** | Cities | 0.071 | 0.106*** | 0.070 | 0.201 |
| | (0.184) | | (0.098) | (0.027) | (0.101) | (0.137) |
| Fixed broadband speed | 1.030*** | Towns | 0.350*** | 0.122*** | -0.060 | 0.005 |
| | (0.011) | | (0.097) | (0.028) | (0.099) | (0.135) |
| Cell C | -1.444*** | Age 26-50 | 0.293*** | 0.326*** | -0.257*** | -0.443*** |
| | (0.086) | | (0.065) | (0.026) | (0.068) | (0.082) |
| MTN | 0.068 | Age 51-65 | 1.110*** | 0.043 | -0.407*** | -0.882*** |
| | (0.089) | | (0.063) | (0.031) | (0.066) | (0.088) |
| Telkom Mobile | -4.227*** | Age 66+ | 1.929*** | -0.371*** | -0.490*** | -1.495*** |
| | (0.096) | | (0.066) | (0.040) | (0.071) | (0.116) |
| Vodacom | 0.010 | High school+ | 0.526*** | 0.949*** | -0.293*** | 0.018 |
| | (0.087) | | (0.043) | (0.025) | (0.045) | (0.070) |
| Mobile data | 2.535*** | Rent | -0.787*** | 0.120*** | -0.013 | 0.360*** |
| | (0.017) | | (0.051) | (0.025) | (0.054) | (0.069) |
| Residuals - voice | 1.065*** | Working | -0.303*** | 0.720*** | 0.052 | 0.283*** |
| | (0.031) | | (0.061) | (0.028) | (0.063) | (0.079) |
| Residuals - data | 0.001*** | Self-employed | 0.243* | 0.064 | 0.057 | 0.424*** |
| | (0.000) | | (0.098) | (0.051) | (0.099) | (0.111) |
| Fixed voice * work telephone | 0.401*** | Coloured | 1.214*** | -0.286*** | -0.319* | -0.883*** |
| | (0.026) | | (0.144) | (0.072) | (0.150) | (0.176) |
| Fixed data * console | 0.619*** | Indian | 1.727*** | -0.214* | -0.560*** | -1.207*** |
| | (0.026) | | (0.149) | (0.085) | (0.155) | (0.178) |
| | | White | 1.310*** | 0.434*** | -0.415** | -0.480** |
| | | | (0.145) | (0.075) | (0.150) | (0.170) |
| | | Income 3-8 | 0.338*** | 0.019 | -0.163* | -0.465*** |
| | | | (0.057) | (0.026) | (0.065) | (0.123) |
| | | Income 8-16 | 0.536*** | 0.039 | -0.339*** | -0.444*** |
| | | | (0.064) | (0.035) | (0.071) | (0.111) |
| | | Income 16+ | 0.728*** | 0.231*** | -0.471*** | -0.217+ |
| | | | (0.080) | (0.051) | (0.085) | (0.116) |
| | | Afrikaans | -0.743*** | -0.256*** | 0.124* | -0.152* |
| | | | (0.056) | (0.045) | (0.059) | (0.074) |
| | | Zulu+ | 0.041 | 0.148* | -0.363* | -0.584** |
| | | | (0.160) | (0.073) | (0.166) | (0.193) |
| | | Xhosa | -0.545** | -0.225** | 0.159 | -0.262 |
| | | | (0.168) | (0.073) | (0.175) | (0.209) |
| | | Sesotho+ | -0.275+ | 0.097 | -0.279+ | -0.345* |
| | | | (0.141) | (0.071) | (0.146) | (0.172) |
| | | Female | 0.594*** | 0.546*** | -0.462*** | -0.418*** |
| | | | (0.038) | (0.021) | (0.040) | (0.054) |
| | | Hh size | -0.104* | -0.694*** | 0.013 | 0.067 |
| | | | (0.051) | (0.027) | (0.053) | (0.069) |
| | | Hh earners | 0.284*** | -0.503*** | -0.088+ | -0.245*** |
| | | | (0.044) | (0.024) | (0.046) | (0.063) |
| | | Hh cells | -0.372*** | 2.232*** | 0.323*** | 0.504*** |
| | | | (0.046) | (0.025) | (0.050) | (0.090) |

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

expected negative signs. The coefficients on the dummy variable for having a fixed connection and dummy variables for mobile operators cannot be directly interpreted because of the interaction terms with consumer characteristics shown in columns (2) and (3) and are discussed below. The utility of having a fixed connection is higher for greater broadband speed. Having mobile data increases the utility of mobile access. The residuals from the first-stage regressions are positive and significant which indicates that there is a positive correlation between prices and consumer choices of mobile voice and data services. The inclusion of the residuals from the control function regressions results in a significantly more negative mobile voice price coefficient but does not affect the price coefficients on mobile data or fixed services.

The coefficients on the fixed voice and fixed data shifters are significant and positive as expected. They increase the utility of having fixed access but not mobile access, which allows us to identify the $\Gamma_{ir}$ parameters. The stand-alone gamma coefficient shows that fixed and mobile voice are complements ($\Gamma_v > 0$), while fixed and mobile data services are substitutes ($\Gamma_d < 0$). As shown in columns (4) and (5), the individual-specific gamma coefficients vary considerably. In particular, having a computer not only makes having a fixed or mobile service more likely but also results in complementarity between fixed and mobile data services given that $-1.400 + 1.461 = 0.061$. Having internet at work or school reduces substitution between fixed and mobile data since $-1.400 + 0.432 = -0.968$. This may be due to learning effects, such as learning the benefits of high-volume data use at work or at an educational facility (see Liu et al., 2010). Note that we do not interact having a computer or having internet access at work or school with the fixed and mobile voice gamma since these two attributes are unlikely to shift utility for voice services.

There is heterogeneity between consumers across a number of dimensions. First, older consumers are more likely to take up a fixed line service and are less likely to take up a mobile service (at least above the age of 65). This is consistent with the findings of Macher et al. (2012), who suggest that older consumers tend to spend time at home, and are therefore more likely to use a fixed line. The opposite is true of younger consumers, who tend to be more mobile. Fixed and mobile data services are stronger substitutes among older consumers compared to those between the ages of 15 and 25, and this effect intensifies with age. At the same time, fixed and mobile voice are weaker complements for older consumers.

Individuals that have a high school (twelve years) or higher education are more likely to choose a fixed or mobile service and are also more likely to see fixed and mobile voice services as substitutes. There is no significant effect on the gamma for fixed and mobile data. Renters are less likely than home-owners to take up fixed-line services and are more likely to take up mobile services. This result is intuitive, in that 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 term-commitment. At the same time, renters are more likely to see fixed and mobile data services as weaker substitutes since $-1.400 + 0.360 = -1.040$.

Employed individuals are less likely to choose a fixed service, perhaps because they are not at home as much to use it. But self-employed consumers are more likely to choose a fixed line because they are more likely to work from home. Being employed and being self-employed in particular mean that fixed and mobile data services are weaker substitutes.

Higher-income consumers are more likely to choose a fixed or mobile service. They see fixed and mobile voice services as weaker complements, and see fixed and mobile data as stronger substitutes. It may be that higher income consumers are more willing to pay the high usage price associated with mobile data even when at home, thus reducing the utility from adding a fixed-line data service.

This income-related pattern is also observed among race and language groups, where Indian, Coloured and White consumers are more likely to take up a fixed line service than Black consumers. White consumers are more likely than Black consumers to take up mobile. Afrikaans and Xhosa-speaking consumers are less likely to take up fixed or mobile services than English-speaking consumers. Similarly, Indian, Coloured and White consumers are all more likely than Black consumers to see fixed and mobile as substitutes, whether for voice or for data.

Being female means taking up a fixed or mobile service is more likely. At the same time, females see fixed and mobile voice as weaker complements and fixed and mobile data as stronger substitutes. Individuals in larger households are less likely to take up fixed and mobile services, possibly due to larger households being associated with lower average incomes in South Africa, where children cluster around old-age social pension recipients (see Duflo, 2000).

The number of cellphones in a household makes taking up a mobile service more likely, which is consistent with evidence on the presence of network effects in mobile adoption (see

Doganoglu and Grzybowski, 2007). A greater number of cellphones in a household is associated with stronger complementarity in respect of voice and weaker substitution with respect to data services. This is likely because fixed-line services enable more fixed to mobile calls and have greater capacity for cellphones to connect to broadband at home.

Our results suggest that there is considerable heterogeneity among individuals in respect of the complementarity or substitutability of fixed and mobile services, as illustrated on Table 21. In particular, 15% of consumers with a computer, and 27% of consumers that have an internet connection at work or school, see fixed and mobile data services as complements. Substitutability or complementarity also varies substantially by income level and race. While 50% of low-income consumers and 39% of Black and 29% of Coloured consumers see fixed and mobile voice as complementary, only 6% of high-income consumers and only 7% of White consumers do. The reverse is true for data services: while 13% of high-income consumers see fixed and mobile data services as complements, only 2% of the lowest-income group do. Almost 50% of young people see fixed and mobile voice as complements, though this effect dissipates with age. Overall, the pattern of proportions of consumers that see fixed and mobile voice and data services as substitutes or complements follows the discussion on the estimation results above.

These results have important implications for developing countries, where interventions intended to bridge the 'digital divide' are focused on mobile services. Our results suggest that fixed lines are needed together with mobile services at higher levels of employment and when there is access to the internet at work or school and greater access to computers.

### 4.6.2 Counterfactual simulations

We use our model to conduct counterfactual simulations in order to illustrate the effects on broadband penetration of (i) reducing mobile data prices by 10%, (ii) expanding fixed line coverage, (iii) rolling out computers, and (iv) expanding internet access at schools and workplaces (as shown in Table 22 and Table 23). The results of this analysis show what might have been possible if Telkom had continued the expansion of fixed-line coverage and met its coverage obligations in the early 2000s (as discussed in Hodge, 2005). In addition, it was intended that the fixed-line network would play an important role in providing access to the internet, facilitated

**Table 21: Percentage of respondents that view fixed and mobile as complements ($\Gamma_{ir}$>0)**

| | (1) Fixed & mobile voice | (2) Fixed & mobile voice & data | (3) N |
|---|---|---|---|
| No computer | 32 | 0 | 90,540 |
| Computer | 13 | 15 | 44,202 |
| No Internet at work/school | 27 | 3 | 121,203 |
| Internet at work/school | 13 | 27 | 13,539 |
| Income <3,000 | 50 | 2 | 30,871 |
| Income 3-7,999 | 34 | 2 | 37,743 |
| Income 8-15,999 | 15 | 4 | 33,081 |
| Income >15,999 | 6 | 13 | 33,047 |
| Black | 39 | 6 | 69,334 |
| Coloured | 29 | 1 | 19,398 |
| Indian | 2 | 0 | 8,981 |
| White | 7 | 7 | 37,029 |
| Afrikaans | 20 | 4 | 36,748 |
| English | 8 | 8 | 31,487 |
| Zulu, Swazi, Ndebele | 24 | 3 | 20,807 |
| Xhosa | 73 | 5 | 15,558 |
| Sth., Tsw., Tsn., Ven., Oth. | 29 | 5 | 30,142 |
| Age < 26 years | 49 | 10 | 39,098 |
| Age 26-50 years | 20 | 5 | 59,851 |
| Age 51-65 years | 12 | 0 | 23,117 |
| Age > 65 years | 6 | 0 | 12,676 |
| No or some High School | 43 | 2 | 61,467 |
| High School or more | 11 | 8 | 73,275 |
| Unemployed | 30 | 3 | 80,866 |
| Employed | 20 | 8 | 53,876 |
| Not self-employed | 27 | 4 | 121,874 |
| Self-employed | 19 | 15 | 12,868 |
| Rural | 38 | 1 | 21,031 |
| Towns | 19 | 6 | 67,915 |
| Cities | 31 | 6 | 45,796 |
| Home owned | 27 | 4 | 101,812 |
| Home rented | 23 | 10 | 32,930 |
| Male | 42 | 9 | 67,171 |
| Female | 10 | 2 | 67,571 |
| Household size <=2 | 19 | 4 | 45,520 |
| Household size > 2 | 29 | 5 | 89,222 |
| 1 earner in household | 32 | 4 | 62,430 |
| 2+ earners in household | 20 | 6 | 72,312 |
| <=1 cell in household | 22 | 1 | 35,311 |
| >1 cellphone in household | 27 | 6 | 99,431 |
| Entire sample | 27 | 5 | 134,742 |

For each individual, we add the $\Gamma_{ir}$ for each main effect and each control (interaction). Columns 1 and 2 show the percentage of the group (row) who view fixed and mobile as complements ($\Gamma_{ir} > 0$), for (1) voice and (2) voice and data for each demographic variable. The total number of survey respondents belonging to the demographic variable category is shown in column 3, and the total observations in respect of columns 1, 2 and 3 are shown in the bottom row.

Table 22: **Fixed-line broadband penetration in counterfactual scenarios in 2014**

| | (1) Base | (2) -10% price | 100% fixed line coverage (3) Base | (4) Computers | (5) Maximum |
|---|---|---|---|---|---|
| No computer | 7.7 | 7.3 | 10.6 | 22.0 | 27.3 |
| Computer | 47.2 | 47.0 | 48.3 | 48.3 | 54.8 |
| No Internet at work/school | 20.4 | 20.1 | 22.8 | 30.1 | 36.3 |
| Internet at work/school | 39.1 | 39.0 | 40.4 | 47.4 | 47.4 |
| Income <3,000 | 11.7 | 11.5 | 15.9 | 23.2 | 27.7 |
| Income 3-7,999 | 8.7 | 8.3 | 12.1 | 20.5 | 25.3 |
| Income 8-15,999 | 20.3 | 19.8 | 21.8 | 30.3 | 36.5 |
| Income >15,999 | 43.2 | 42.9 | 43.6 | 49.0 | 56.0 |
| Black | 7.8 | 7.7 | 11.5 | 19.4 | 25.2 |
| Coloured | 20.4 | 19.9 | 23.0 | 30.5 | 35.5 |
| Indian | 40.2 | 39.5 | 40.8 | 48.2 | 53.6 |
| White | 44.0 | 43.5 | 44.0 | 50.1 | 56.3 |
| Afrikaans | 28.0 | 27.4 | 29.2 | 35.9 | 41.5 |
| English | 44.5 | 44.0 | 45.0 | 51.8 | 57.9 |
| Zulu, Swazi, Ndebele | 7.9 | 7.8 | 11.7 | 20.2 | 26.1 |
| Xhosa | 6.4 | 6.3 | 10.4 | 17.6 | 22.6 |
| Sth., Tsw., Tsn., Ven., Oth. | 6.9 | 6.8 | 10.6 | 18.5 | 24.2 |
| Age < 26 years | 17.7 | 17.6 | 19.8 | 27.2 | 33.8 |
| Age 26-50 years | 18.8 | 18.7 | 20.9 | 28.1 | 34.2 |
| Age 51-65 years | 27.4 | 26.8 | 30.1 | 37.8 | 43.1 |
| Age > 65 years | 34.7 | 33.4 | 37.9 | 44.7 | 47.4 |
| No or some High School | 11.0 | 10.7 | 14.6 | 22.0 | 26.4 |
| High School or more | 29.9 | 29.6 | 31.3 | 38.5 | 45.2 |
| Unemployed | 19.3 | 18.8 | 22.0 | 29.4 | 34.9 |
| Employed | 25.4 | 25.2 | 27.1 | 34.3 | 40.3 |
| Not self-employed | 19.9 | 19.6 | 22.3 | 29.6 | 35.2 |
| Self-employed | 38.8 | 38.6 | 40.5 | 47.7 | 54.8 |
| Rural | 6.1 | 6.0 | 11.1 | 18.5 | 23.1 |
| Towns | 28.2 | 27.8 | 29.7 | 36.7 | 42.7 |
| Cities | 18.9 | 18.6 | 21.2 | 29.0 | 34.8 |
| Home owned | 23.6 | 23.2 | 26.1 | 33.6 | 39.3 |
| Home rented | 16.1 | 16.0 | 17.6 | 24.5 | 30.2 |
| Male | 22.1 | 21.8 | 24.2 | 31.3 | 36.9 |
| Female | 21.5 | 21.1 | 23.9 | 31.5 | 37.3 |
| Household size <=2 | 24.8 | 24.4 | 26.8 | 34.1 | 39.2 |
| Household size > 2 | 20.1 | 19.8 | 22.6 | 29.9 | 36.0 |
| 1 earner in household | 15.6 | 15.4 | 18.2 | 25.7 | 31.4 |
| 2+ earners in household | 26.5 | 26.1 | 28.6 | 35.8 | 41.6 |
| <=1 cell in household | 15.3 | 14.8 | 19.2 | 26.6 | 30.3 |
| >1 cellphone in household | 23.5 | 23.2 | 25.4 | 32.7 | 39.0 |
| Total fixed voice and data | 21.8 | 21.4 | 24.1 | 31.4 | 37.1 |

In column (1), base scenario probabilities are shown for fixed broadband and in (2) penetration if mobile data prices were reduced by 10% are shown. In column (3), probabilities assuming 100% fixed-line coverage are shown. In column (4), probabilities if there were 100% fixed-line coverage and all individuals had a computer are shown. In column (5), probabilities assuming 100% fixed-line coverage, 100% have computers and all individuals had internet at work or school are shown.

Table 23: **Mobile broadband penetration (%) in counterfactual scenarios in 2014**

| | (1) Base | (2) -10% price | 100% fixed line coverage (3) Base | (4) Computers | (5) Maximum |
|---|---|---|---|---|---|
| No computer | 58.3 | 61.9 | 57.1 | 59.1 | 62.0 |
| Computer | 74.9 | 76.9 | 74.8 | 74.8 | 78.0 |
| No Internet at work/school | 63.1 | 66.2 | 62.3 | 63.5 | 66.8 |
| Internet at work/school | 78.4 | 80.3 | 78.3 | 79.7 | 79.7 |
| Income <3,000 | 55.3 | 59.2 | 53.9 | 55.8 | 59.4 |
| Income 3-7,999 | 59.7 | 63.3 | 58.4 | 59.5 | 62.0 |
| Income 8-15,999 | 65.0 | 67.9 | 64.5 | 65.8 | 68.6 |
| Income >15,999 | 74.1 | 76.2 | 74.0 | 75.1 | 78.4 |
| Black | 64.9 | 68.2 | 63.7 | 65.0 | 67.4 |
| Coloured | 59.3 | 62.5 | 58.4 | 59.5 | 62.8 |
| Indian | 61.1 | 63.8 | 60.9 | 62.5 | 66.5 |
| White | 66.2 | 68.9 | 66.2 | 67.4 | 71.1 |
| Afrikaans | 61.7 | 64.8 | 61.3 | 62.3 | 65.6 |
| English | 66.6 | 69.1 | 66.5 | 68.0 | 71.9 |
| Zulu, Swazi, Ndebele | 65.2 | 68.5 | 63.9 | 65.1 | 67.4 |
| Xhosa | 62.7 | 66.0 | 61.5 | 62.9 | 65.4 |
| Sth., Tsw., Tsn., Ven., Oth. | 64.5 | 67.9 | 63.3 | 64.7 | 67.2 |
| Age < 26 years | 72.4 | 74.7 | 71.8 | 73.2 | 75.8 |
| Age 26-50 years | 69.2 | 72.0 | 68.6 | 69.7 | 72.2 |
| Age 51-65 years | 55.1 | 59.1 | 54.1 | 55.4 | 59.3 |
| Age > 65 years | 37.9 | 42.3 | 36.7 | 38.4 | 43.5 |
| No or some High School | 54.7 | 58.6 | 53.4 | 54.9 | 58.2 |
| High School or more | 71.4 | 73.8 | 71.0 | 72.2 | 75.0 |
| Unemployed | 59.6 | 62.9 | 58.7 | 60.0 | 63.3 |
| Employed | 70.9 | 73.5 | 70.4 | 71.7 | 74.2 |
| Not self-employed | 63.4 | 66.5 | 62.6 | 63.9 | 66.9 |
| Self-employed | 71.3 | 73.9 | 70.8 | 72.4 | 75.9 |
| Rural | 57.9 | 61.9 | 56.1 | 57.7 | 60.6 |
| Towns | 66.7 | 69.4 | 66.2 | 67.4 | 70.5 |
| Cities | 63.2 | 66.3 | 62.4 | 63.8 | 66.7 |
| Home owned | 62.9 | 66.1 | 62.1 | 63.3 | 66.5 |
| Home rented | 68.1 | 70.9 | 67.7 | 69.1 | 71.6 |
| Male | 64.0 | 67.0 | 63.3 | 64.7 | 67.8 |
| Female | 64.4 | 67.5 | 63.5 | 64.7 | 67.7 |
| Household size <=2 | 60.5 | 63.8 | 59.9 | 61.3 | 64.6 |
| Household size > 2 | 66.2 | 69.1 | 65.4 | 66.6 | 69.4 |
| 1 earner in household | 63.5 | 66.8 | 62.7 | 64.1 | 67.0 |
| 2+ earners in household | 64.7 | 67.6 | 64.0 | 65.2 | 68.3 |
| <=1 cell in household | 48.4 | 52.3 | 47.1 | 49.8 | 54.5 |
| >1 cellphone in household | 68.4 | 71.3 | 67.8 | 68.7 | 71.3 |
| Total mobile voice and data | 64.2 | 67.3 | 63.4 | 64.7 | 67.7 |

In column (1), base scenario probabilities are shown for mobile broadband and in (2) penetration if mobile data prices were reduced by 10% are shown. In column (3), probabilities assuming 100% fixed-line coverage are shown. In column (4), probabilities if there were 100% fixed-line coverage and all individuals had a computer are shown. In column (5), probabilities assuming 100% fixed-line coverage, 100% have computers and all individuals had internet at work or school are shown.

by local loop unbundling.[51] The costs of rolling out fixed lines are likely affordable, even for low-income households, due to relatively low labour costs in South Africa and the large number of fibre to the home operators. For example, one challenger fibre operator in South Africa plans to roll out fibre to the home using exisitng pole infrastructure in a large low-income community in Johannesburg at a price of R80 per month.[52]

Furthermore, while we do not comment on the debate in the literature on the impact of computers at home and at schools on educational outcomes, our simulations are useful in that they may help us understand the means by which the 'digital divide' might be bridged. The 'digital divide' may be especially large in South Africa, where fixed-lines were rolled out mainly to White households during apartheid and fixed-line broadband today is available mostly in the same areas. For example, there is evidence that technology use in schools has positive effects on educational outcomes in developing countries (Banerjee et al., 2007).[53] In addition, there are some papers that show that using technology at home improves educational outcomes, though the evidence overall is mixed. There is stronger evidence that having a computer at home improves computer skills (see, for example, Malamud and Pop-Eleches, 2011), which is unsurprising. Having a computer at home and access to computers and the internet at schools and workplaces therefore plays a role in the development of human capital, particularly in developing countries. Providing access to the internet at schools and workplaces is not likely to be very costly, since most communities that have schools have mobile network coverage, and the mobile operators in South Africa use fixed-lines (often fibre) for backhaul to a large extent. Rolling out computers to households would likely be more costly, since only around 22% of 16.2m households have a computer. Such an intervention would nonetheless likely be affordable using more recent low-cost computer technologies combined with the fact that 82% of households have a television in South Africa.[54]

[51] Local loop unbundling was first recommended in a report prepared by the Ministry of Communications, among others, entitled: "Local loop unbundling. A way forward for South Africa.". This was recommended again in the broadband policy issued by government in 2013, entitled "South Africa Connect: Creating opportunities, ensuring inclusion. South Africa's Broadband Policy".

[52] The operator concerned, Vumatel, has rolled out an extensive fibre network in higher-income areas since 2015, together with more than 30 other new fibre to the home entrants across South Africa.

[53] There is some evidence of this effect in developed countries (see, for example, Goolsbee and Guryan, 2006). The effect in developing countries may be due to high-levels of absenteeism among school teachers, which means that students are receiving a lower-quality education than in developed countries (Bulman and Fairlie, 2016). Chaudhury et al. (2006) find that teacher absenteeism in a study on Bangladesh, Ecuador, India, Indonesia, Peru and Uganda was 19% on average.

[54] Source: Statistics South Africa, "General Household Survey", 2017, statistical release P0318. A Raspberry

The results of our simulations are as follows. First, a 10% reduction in mobile data prices results in only a small reduction fixed line data penetration, from 21.8% to 21.4%, reflecting the fact the fixed and mobile data services are complements rather than substitutes for large numbers of consumers. Second, expansion of fixed-line coverage (from two thirds to the entire sample) increases fixed-line voice and data penetration but only to a limited extent, from 21.8% to 24.1%. Consumers currently living outside of fixed-coverage areas are unlikely to take up fixed-line services even if they were rolled out. Third, if all consumers were given a computer, fixed broadband penetration would increase to 31.4%, and if in addition all individuals were able to connect to the internet at work or school, fixed broadband penetration at home would increase to 37.1%. Overall, these interventions would result in a gain of 15.3 percentage points in fixed-line broadband penetration.

These outcomes vary depending on various demographic characteristics including income, race and language (see Table 22). For example, expanding fixed-line coverage, access to computers and internet access at school and work would increase fixed-line broadband penetration among Black individuals by 17.4 percentage points from 7.8% to 25.2% but would expand access among White consumers by 12.3 percentage points, from 44% to 56.3%. In expanding internet penetration among particularly poor households, increasing access to fixed lines, computers and internet at work or school may help to reduce the 'digital divide'.

At the same time, a 10% reduction in mobile data prices results in an increase in mobile broadband penetration of only 3.1 percentage points. Due to the complementary nature of fixed and mobile data services for large numbers of individuals, expanding fixed-line data coverage reduces the probability of choosing mobile data by only 0.8%. Expanding access to computers and internet connections at work or school expands demand for mobile data services (Table 23). Computers result in only a small gain in mobile data access (1.3 percentage points). However, computers and access to the internet at work or school result in an expansion of mobile data services by 3.5 percentage points. These benefits are reasonably evenly spread among income and race groups.

The gain from a 10% mobile data price reduction, in increasing mobile broadband penetration by 3.1 percentage points, is relatively modest compared to gains from expanding access to fixed-

Pi for example is available in South Africa for R235, a keyboard and mouse for R100, and both can be connected to even old television sets via the 3.5mm jack.

line broadband, computers and internet at work or school. The latter interventions result in a similar (3.5 percentage point) expansion in mobile data penetration but also expand fixed-line broadband penetration, which allows for significantly higher usage volumes at lower prices per gigabyte, by 15.3 percentage points. In addition, expanding fixed internet access at homes in South Africa expands individual access to the internet considerably more than mobile services, given the relatively large average household size of 3.3 people in South Africa (rising to 4.3 in rural areas).[55]

The gains from an increase in fixed-line coverage, ensuring that all households have a computer and that workplaces and education facilities have internet connections available to individuals are therefore more important than reductions in retail mobile data prices.

## 4.7 Conclusion

We estimate a discrete-choice model of fixed and mobile substitution for voice and data services in a developing country with high levels of poverty and inequality, South Africa. Our model provides for flexible, individual-level variation in utility derived from fixed and mobile voice services, and fixed and mobile data services. Our results show that fixed and mobile substitution or complementarity depends on a range of individual and household characteristics. We find that half of lower-income consumers see fixed and mobile voice services as complements though only 2% see fixed and mobile data services as complements. The pattern is reversed for high-income consumers, only 6% of who see fixed and mobile voice as complements but 13% of who see fixed and mobile data as complements.

We use our model to conduct counterfactual simulations in order to illustrate the effects on broadband penetration of (i) reducing mobile data prices by 10%, (ii) expanding fixed line coverage, (iii) rolling out computers, and (iv) expanding internet access at schools and workplaces. If mobile data prices were 10% lower, mobile data penetration would increase by only 3.1 percentage points and because fixed and mobile data are complements for large numbers of consumers, fixed-line penetration would decline by a relatively modest 0.4 percentage points. However, if fixed-line coverage were expanded to the entire population and computers were available to all, fixed-line broadband penetration would increase significantly by 9.6 percentage points

[55]Source: Statistics South Africa, 2017, "Living Conditions of Households in South Africa", statistical release P0310.

and mobile broadband penetration would increase by half of a percentage point. Furthermore, having an internet connection at work or school would add an additional 5.7 percentage points to fixed-line broadband penetration, and 3 percentage points to mobile broadband penetration. These results suggest that expanding fixed-line coverage, access to computers and internet at work and schools are more important than reducing mobile data prices by 10%.

Though we do not estimate the impact of broadband penetration on employment, an important finding of this research is that being employed, and being self-employed in particular, makes fixed and mobile data services weaker substitutes. Unemployment in South Africa is currently over 37%.[56] At higher levels of employment and particularly self-employment, more fixed-line services will be needed. This is important in view of the results reported by Hjort and Poulsen (forthcoming), who show that the expansion of high-speed internet access in African countries, including South Africa, results not only in greater employment but also in greater productivity.

These results have several implications for regulators and policymakers in developing countries, particularly in Africa, who are focused largely on interventions in respect of mobile data services. Firstly, it is more important to stimulate demand for broadband services by providing the tools for using them (such as a computer) as it is to reduce the prices of mobile data services. This means that policymakers and regulators might consider activities that ensure that individuals have access to computers and internet at work and educational facilities in order to increase broadband adoption. Second, we find that fixed and mobile are complements for large groups of consumers. The number of consumers that see fixed and mobile data as complements is greater at higher levels of employment and self-employment, and with more access to computers and greater connectivity at work and at schools. This suggests that relying solely on mobile networks to bridge the 'digital divide' is not enough. Policymakers and regulators might consider means of expanding access to computers and internet at workplaces and schools together with expanding access to fixed-line broadband.

[56]Using the expanded definition, i.e. including those who would take a job if offered even though they did not actively seek work in the past month. Source: Statistics South Africa, 2018, "Quarterly Labour Force Survey", statistical release P0211.

# 5 Conclusion

The effects of consumer heterogeneity on the impact of competition and regulation in the telecommunications sector are explored here in three contributions. First, a unique dataset on 2,773 fixed and mobile prices is collected and studied in order to test the effects of the regulation of mobile termination rates (MTRs) on retail prices. The results of this analysis show that cost-based regulation of MTRs, the rates that operators pay one another to terminate voice calls, resulted in lower retail prices in South Africa. While both prepaid and postpaid prices declined by over 40% between 2009 and 2017, the period in which the regulation was introduced, only 30% of this decline can be attributed to lower termination costs in the case of prepaid prices (mostly used by low-income consumers). In the case of postpaid (used more by higher-income consumers), 60% of the decline can be attributed to lower termination costs. The regulation of MTRs also reduced the ability of incumbent operators that likely have market power (MTN and Vodacom) to discriminate between on-net and off-net prices, generating 'tariff-mediated network effects' that could lead to the exclusion of smaller rivals. This suggests that policymakers and regulators in developing countries could consider reducing mobile termination rates and might also consider intervening in respect of on-net and off-net discounts. This research extends the existing literature by evaluating a detailed retail price dataset, where existing literature uses aggregate, country level data (such as the widely-cited paper by Genakos and Valletti, 2011). This provides more information on what happens when wholesale termination rates decline, including the impact on on-net and off-net pricing differentials, which has not been analysed before as far as I am aware. At the same time, this research would be improved by collecting even more data on prices and product characteristics, and in addition on what price options consumers actually chose, studied by Nicolle et al. (2018) for example.

In the second contribution, we find that high-income consumers benefit from a greater increase in consumer surplus than low-income consumers as a result of the regulation of MTRs or new entry in the mobile sector. At the same time, mobile adoption increases more among low-income consumers than among high-income consumers. We also find that addressing market power through MTR regulation has a greater effect on consumer welfare than introducing new entrants does. In order to study this, we developed a structural model of supply and demand for mobile voice services, and we computed changes in consumer surplus after entry and with regulation. Our results suggest that regulators in developing countries could focus at least as much on regulating market power as on introducing new entrants, such as through spectrum assignments. In addition, more could be done to ensure that low-income consumers benefit from new entry, such as by imposing obligations on operators to extend network coverage to low-income areas. This contribution develops several strands of the economics literature, including on the link between telecommunications and economic development, discrete choice modelling of choices of telecommunications services, the impact of regulation and the impact of competition on welfare. While previous papers have analysed the impact of competition and regulation, we are not aware of any that have done so taking into account consumer heterogeneity. We estimate a mixed-logit model which allows for highly flexible substitution patterns among consumers. Furthermore, previous papers typically consider developed countries, which do not have the same high levels of poverty and inequality as is the case in developing countries like South Africa. This research could be improved using better data on the precise choices made by consumers in respect of pricing plans and on usage of services. Furthermore, it would be useful to understand the importance of consumers choosing not one but two or more mobile networks to connect to.

In a third contribution, we find that fixed and mobile voice and data services are complements rather than substitutes for large numbers of consumers. This is particularly the case among higher-income, employed, and especially self-employed consumers that have a computer or internet connection at work or school. We show in counterfactual simulations that in order to drive broadband penetration in developing countries, it is at least as important to provide access to computers and internet access at workplaces and schools as it is to reduce retail mobile prices by 10%. This means that the focus on mobile services by regulators and policymakers in developing countries, including the regulation of mobile services, may not be enough to bridge the 'digital divide'. The roll-out of fixed lines or the regulation of market power in the fixed line sector may also be needed. This is the first paper we are aware of that studies fixed and mobile substitution in a developing country like South Africa, where there is significant consumer heterogeneity due to the high levels of inequality. Our model allows for significant flexibility in consumer choices of fixed and mobile services, allowing the services to be complements or substitutes at the level of the individual. A limitation of this research is a lack of data on tariff plan choices and usage of telecommunications services by individual consumers. Furthermore, consumers may have more than one mobile network provider, and therefore may choose different operators for their smartphone and laptop data connections, for example. Finally, this research would benefit from data on the uptake and usage of new optical fibre network services and fixed-wireless replacement services, which have recently grown in importance.

## References

Aker, J. C. (2010). “Information from markets near and far: Mobile phones and agricultural markets in Niger”. In: *American Economic Journal: Applied Economics* 2.3, pp. 46–59.

Aker, J. C. and I. M. Mbiti (2010). “Mobile phones and economic development in Africa”. In: *Journal of Economic Perspectives* 24.3, pp. 207–32.

Aproskie, J., J. Hodge, R. Lipschitz, and F. Sheik (2008). *South African 15-year Telecommunications Policy Review.*

Argent, J. and T. Begazo (2015). *Competition in Kenyan markets and its impact on income and poverty: a case study on sugar and maize.* The World Bank.

Armstrong, M. (1998). “Network Interconnection in Telecommunications”. In: *The Economic Journal* 108.448, pp. 545–564.

Armstrong, M. and J. Wright (2009). “Mobile Call Termination”. In: *The Economic Journal* 119.538, F270–F307.

Baker, J. B. and S. C. Salop (2015). “Antitrust, competition policy, and inequality”. In: *Georgetown Law Journal Online* 104, p. 1.

Banerjee, A. V., S. Cole, E. Duflo, and L. Linden (2007). “Remedying education: Evidence from two randomized experiments in India”. In: *The Quarterly Journal of Economics* 122.3, pp. 1235–1264.

Berry, S. et al. (2014). “Structural models of complementary choices”. In: *Marketing Letters* 25.3, pp. 245–256.

Björkegren, D. (2018). “The Adoption of Network Goods: Evidence from the Spread of Mobile Phones in Rwanda”. In: *The Review of Economic Studies*, rdy024.

Blimpo, M. P., M. Minges, W. A. Kouamé, T. T. Azomahou, E. K. K. Lartey, C. Meniago, M. M. Buitano, and A. G. Zeufack (2017). *Leapfrogging : the key to Africa’s development - from constraints to investment opportunities (English).* Tech. rep. Washington, D.C. : World Bank Group.

Briglauer, W., A. Schwarz, and C. Zulehner (2011). “Is fixed-mobile substitution strong enough to de-regulate fixed voice telephony? Evidence from the Austrian markets”. In: *Journal of Regulatory Economics* 39.1, pp. 50–67.

Bulman, G. and R. W. Fairlie (2016). "Technology and education: Computers, software, and the internet". In: *Handbook of the Economics of Education*. Vol. 5. Elsevier, pp. 239–280.

Calandro, E. and C. Chair (2016). "Policy and regulatory challenges posed by emerging pricing strategies". In: *Information Technologies & International Development* 12.2, pp–13.

Calzada, J. and T. M. Valletti (2008). "Network competition and entry deterrence". In: *The Economic Journal* 118.531, pp. 1223–1244.

Cardona, M., A. Schwarz, B. B. Yurtoglu, and C. Zulehner (2009). "Demand estimation and market definition for broadband Internet services". In: *Journal of Regulatory Economics* 35.1, pp. 70–95.

Chaudhury, N., J. Hammer, M. Kremer, K. Muralidharan, and F. H. Rogers (2006). "Missing in action: teacher and health worker absence in developing countries". In: *Journal of Economic perspectives* 20.1, pp. 91–116.

Court, A. (1939). "Hedonic price indexes with automobile examples". In: *The dynamics of the automobile demand*.

Czernich, N., O. Falck, T. Kretschmer, and L. Woessmann (2011). "Broadband infrastructure and economic growth". In: *The Economic Journal* 121.552, pp. 505–532.

Deaton, A. (1988). "Quality, quantity, and spatial variation of price". In: *The American Economic Review*, pp. 418–430.

Dessein, W. (2003). "Network competition in nonlinear pricing". In: *RAND Journal of Economics*, pp. 593–611.

— (2004). "Network competition with heterogeneous customers and calling patterns". In: *Information Economics and Policy* 16.3, pp. 323–345.

Doganoglu, T. and L. Grzybowski (2007). "Estimating network effects in mobile telephony in Germany". In: *Information Economics and Policy* 19.1, pp. 65–79.

Duflo, E. (2000). "Child health and household resources in South Africa: evidence from the old age pension program". In: *American Economic Review* 90.2, pp. 393–398.

Economides, N., K. Seim, and V. B. Viard (2008). "Quantifying the benefits of entry into local phone service". In: *the RAND Journal of Economics* 39.3, pp. 699–730.

Forenbacher, I., D. Perakovic, and S. Husnjak (2016). "Hedonic modeling to explore the relationship of cell phone plan price and quality in Croatia". In: *Telematics and Informatics* 33.4, pp. 1057 –1070.

Gans, J. S. and S. P. King (2001). "Using 'bill and keep' interconnect arrangements to soften network competition". In: *Economics Letters* 71.3, pp. 413–420.

Genakos, C. and T. Valletti (2015). "Evaluating a decade of mobile termination rate regulation". In: *The Economic Journal* 125.586.

— (2012). "Regulating prices in two-sided markets: The waterbed experience in mobile telephony". In: *Telecommunications Policy* 36.5. Regulation and competition in communications markets, pp. 360 –368.

— (2011). "Testing the waterbed effect in mobile telephony". In: *Journal of the European Economic Association* 9(6).

Genakos, C., T. Valletti, and F. Verboven (2018). "Evaluating market consolidation in mobile communications". In: *Economic Policy* 33.93, pp. 45–100.

Gentzkow, M. (2007). "Valuing new goods in a model with complementarity: Online newspapers". In: *American Economic Review* 97.3, pp. 713–744.

Goolsbee, A. and J. Guryan (2006). "The impact of Internet subsidies in public schools". In: *The Review of Economics and Statistics* 88.2, pp. 336–347.

Government of South Africa (2016). *National integrated ICT policy white paper.*

Griliches, Z. (1961). "Hedonic Price Indexes for Automobiles: An Econometric of Quality Change". In: *The Price Statistics of the Federal Government*. Ed. by R. of the Price Statistics Review Committee. NBER.

Gruber, H. and P. Koutroumpis (2011). "Mobile telecommunications and the impact on economic development". In: *Economic Policy* 26.67, pp. 387–426.

Grzybowski, L. (2014). "Fixed-to-mobile substitution in the European Union". In: *Telecommunications Policy* 38.7, pp. 601–612.

— (2008). "The impact of regulation on the retail prices in fixed-line telephony across the European Union". In: *Telecommunications Policy* 32.2, pp. 131–144.

Grzybowski, L. and F. Verboven (2016). "Substitution between fixed-line and mobile access: the role of complementarities". In: *Journal of Regulatory Economics* 49.2, pp. 113–151.

Grzybowski, L., R. Nitsche, F. Verboven, and L. Wiethaus (2014). "Market definition for broadband internet in Slovakia – Are fixed and mobile technologies in the same market?" In: *Information Economics and Policy* 28, pp. 39 –56.

Hahn, J.-H. (2004). "Network competition and interconnection with heterogeneous subscribers". In: *International Journal of Industrial Organization* 22.5, pp. 611–631.

Hauge, J. A. and J. E. Prieger (2010). "Demand-side programs to stimulate adoption of broadband: What works?" In: *Review of Network Economics* 9.3.

Hawthorne, R. (2018). "The effects of lower mobile termination rates in South Africa". In: *Telecommunications Policy* 42.5, pp. 374–385.

— (2016). "The impact of the call termination rate reduction on consumer surplus in South Africa". In: *African Journal of Information and Communication* 17.

Hjort, J. and J. Poulsen (forthcoming). "The arrival of fast internet and employment in Africa". In: *American Economic Review.*

Hodge, J. (2005). "Tariff structures and access substitution of mobile cellular for fixed line in South Africa". In: *Telecommunications Policy* 29.7, pp. 493–505.

Hoernig, S., R. Inderst, and T. Valletti (2014). "Calling circles: network competition with nonuniform calling patterns". In: *The RAND Journal of Economics* 45.1, pp. 155–175.

Hurkens, S. and Á. L. López (2014). "Mobile termination, network externalities and consumer expectations". In: *The Economic Journal* 124.579, pp. 1005–1039.

Jensen, R. (2007). "The digital provide: Information (technology), market performance, and welfare in the South Indian fisheries sector". In: *The Quarterly Journal of Economics* 122.3, pp. 879–924.

Jullien, B., P. Rey, and W. Sand-Zantman (2013). "Termination fees revisited". In: *International Journal of Industrial Organization* 31.6, pp. 738–750.

Karamti, C. and L. Grzybowski (2010). "Hedonic study on mobile telephony market in France: pricing–quality strategies". In: *Netnomics* 11.3, pp. 255–289.

Klonner, S. and P. J. Nolen (2010). "Cell Phones and Rural Labor Markets: Evidence from South Africa". eng. In: Proceedings of the German Development Economics Conference, Hannover 2010 56. Göttingen: Verein für Socialpolitik, Ausschuss für Entwicklungsländer.

Knott-Craig, A. (2009). *Interconnect: the real story.* Ed. by TechCentral. [Online; posted 11-August-2009].

Kongaut, C. and E. Bohlin (2014). "Impacts of mobile termination rates on retail prices: the implication for regulators". In: *info* 16.2, pp. 80–93.

Laffont, J.-J., P. Rey, and J. Tirole (1998a). "Network competition: I. Overview and nondiscriminatory pricing". In: *The RAND Journal of Economics*, pp. 1–37.

— (1998b). "Network competition: II. Price discrimination". In: *The RAND Journal of Economics*, pp. 38–56.

Leibbrandt, M., I. Woolard, A. Finn, and J. Argent (2010). "Trends in South African Income Distribution and Poverty since the Fall of Apartheid". In: *OECD Social, Employment and Migration Working Papers* 101.

Liu, H., P. K. Chintagunta, and T. Zhu (2010). "Complementarities and the demand for home broadband internet services". In: *Marketing Science* 29.4, pp. 701–720.

López, Á. L. and P. Rey (2016). "Foreclosing Competition Through High Access Charges and Price Discrimination". In: *The Journal of Industrial Economics* 64.3, pp. 436–465.

Macher, J. T., J. W. Mayo, O. Ukhaneva, and G. A. Woroch (2012). *Demand in a portfolio-choice environment: The evolution of telecommunications.* Tech. rep. Working paper.

Malamud, O. and C. Pop-Eleches (2011). "Home computer use and the development of human capital". In: *The Quarterly Journal of Economics* 126.2, pp. 987–1027.

Mothobi, O. (2017). *The Impact of Telecommunication Regulatory Policy on Mobile Retail Price in Sub-Saharan African Countries.* Tech. rep.

Muto, M. (2012). "The impacts of mobile phones and personal networks on rural-to-urban migration: Evidence from Uganda". In: *Journal of African Economies* 21.5, pp. 787–807.

Muto, M. and T. Yamano (2009). "The impact of mobile phone coverage expansion on market participation: Panel data evidence from Uganda". In: *World development* 37.12, pp. 1887–1896.

Nicolle, A., L. Grzybowski, and C. Zulehner (2018). "Impact of competition, investment and regulation on prices of mobile services: evidence from France". In: *Economic Inquiry.*

Pakes, A. (2003). "A Reconsideration of Hedonic Price Indexes with an Application to PC's". In: *The American Economic Review* 93.5, pp. 1578–1596.

Pereira, P. and T. Ribeiro (2011). “The impact on broadband access to the Internet of the dual ownership of telephone and cable networks”. In: *International Journal of Industrial Organization* 29.2, pp. 283–293.

Petrin, A. and K. Train (2010). “A control function approach to endogeneity in consumer choice models”. In: *Journal of Marketing Research* 47.1, pp. 3–13.

Qiang, C. Z.-W., C. M. Rossotto, and K. Kimura (2009). “Economic impacts of broadband”. In: *Information and communications for development 2009: Extending reach and increasing impact* 3, pp. 35–50.

Research ICT Africa (2010-2015). *RIA African Mobile Pricing 2010-2015*. [dataset]. Cape Town: DataFirst [distributor]. International Development Research Centre [funding agency].

— (2016). *Update: State of prepaid market in South Africa. Submission to the Parliament of South Africa on ‘The Cost to Communicate in South Africa’*.

Rodini, M., M. R. Ward, and G. A. Woroch (2003). “Going mobile: substitutability between fixed and mobile access”. In: *Telecommunications Policy* 27.5 - 6. Compeitition in Wireless: Spectrum, Service and Technology Wars, pp. 457 –476.

Roller, L.-H. and L. Waverman (2001). “Telecommunications infrastructure and economic development: A simultaneous approach”. In: *American economic review* 91.4, pp. 909–923.

Samuelson, P. A. (1974). “Complementarity: An essay on the 40th anniversary of the Hicks-Allen revolution in demand theory”. In: *Journal of Economic literature* 12.4, pp. 1255–1289.

Schöni, O. and L. Seger (2014). *Comparing Mobile Communication Service Prices Among Providers: A Hedonic Approach*. Tech. rep. Université de Fribourg.

Small, K. A. and H. S. Rosen (1981). “Applied welfare economics with discrete choice models”. In: *Econometrica: Journal of the Econometric Society*, pp. 105–130.

South African Audience Research Foundation (SAARF) (2009-2014). *All Media Products Survey 2009 - 2014, Waves 1-4*. [dataset]. Cape Town: DataFirst [distributor].

Southern Africa Labour and Development Research Unit (2008-2016). *National Income Dynamics Study 2008 - 2015, Waves 1-4*. [dataset] versions 6.1(w1), 3.1(w2), 2.1(w3), 1.1(w4). Cape Town: DataFirst [distributor], 2016. Cape Town: Southern Africa Labour and Development Research Unit [implementer], 2016. Pretoria: Department of Planning Monitoring and Evaluation, SA Presidency [funding agency].

Statistics South Africa (2016). *Consumer Price Index - Telecommunications prices*. Report. Obtained through correspondence with Statistics South Africa.

Stork, C. and A. Gillwald (2014). “Link between termination rates and retail prices in Namibia, Kenya and South Africa”. In: *Telecommunications Policy* 38.8-9, pp. 783–797.

Suárez, D. and B. García-Mariñoso (2013). “Which are the drivers of fixed to mobile telephone access substitution? An empirical study of the Spanish residential market”. In: *Telecommunications Policy* 37.4-5, pp. 282–291.

TechCentral.co.za, ed. (2010). *Mobile operators accused of hiking rates on the sly*. [Online; posted 29-June-2010].

Train, K. E., D. L. McFadden, and M. Ben-Akiva (1987). “The demand for local telephone service: A fully discrete model of residential calling patterns and service choices”. In: *The RAND Journal of Economics*, pp. 109–123.

Train, K. (2009). *Discrete choice methods with simulation*. 2nd. Cambridge University Press.

Triplett, J. (2004). *Handbook on Hedonic Indexes and Quality Adjustments in Price Indexes: Special Application to Information Technology Products*. Vol. 2004/09. OECD publishing.

Veronese, B. and M. Pesendorfer (2009). “Wholesale termination regime, termination charge levels and mobile industry performance”. In: *report for Ofcom*.

Vodacom (2009 - 2017). *Annual Reports for financial years between 2009 and 2017*.

Ward, M. and G. Woroch (2010). “The effect of prices on fixed and mobile telephone penetration: Usage price subsidies as natural experiments”. In: *Information economics and policy*.

Ward, M. R. and S. Zheng (2012). “Mobile and fixed substitution for telephone service in China”. In: *Telecommunications Policy* 36.4, pp. 301–310.

Wernick, C., C. Growitsch, and J. S. Marcus (2010). “The Effects of Lower Mobile Termination Rates (MTRs) on Retail Price and Demand”. In: *Communications and strategies* 80.

Wodon, Q. and H. Zaman (2009). “Higher food prices in Sub-Saharan Africa: Poverty impact and policy responses”. In: *The World Bank Research Observer* 25.1, pp. 157–176.