The impact of spectrum prices on consumers Technical Report

September 2019

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1. Introduction

The effect that spectrum prices have on the development of mobile services is disputed. Some argue that high spectrum licence fees can induce operators to reduce capital investments or increase consumer prices. If mobile operators set prices or take investment decisions disregarding fixed costs, they would not be able to make a return on investment. As one-off spectrum fees increase the average cost for mobile operators, in the long term they impact the level at which an operator can make a return on investment. Spectrum fees are – according to this view – fundamental inputs into the investment and pricing decisions made by mobile operators (Noam, 1998; Bauer, 2001).

Others argue that spectrum licence fees are voluntarily incurred, and that, as a sunk cost, they do not influence future decisions a mobile operator makes around where and how quickly to roll out its network, or around its strategies to attract consumers and maximise revenues such as pricing and investment (Cave and Valletti, 2000).

The long-term dispute over the impact of high spectrum prices is particularly important in the context of mobile communications: as a general-purpose technology that has spillover effects into other industries, consumer and market outcomes will have a knock-on impact on a country's productivity growth and economic prosperity.

Despite the strong debate around competing theoretical arguments, little empirical work has been carried out to establish how and whether spectrum prices can impact consumer outcomes. This has been in part affected by a general acceptance that auctions are the most effective process to allocate spectrum and therefore deliver outcomes that guarantee the best development of the industry (Pogorel, 2018).

While auctions can be an effective mechanism to allocate spectrum to those able to extract most value from this scarce and finite resource, they need to be designed effectively if they are to deliver an efficient outcome. Auctions can and often are designed with other objectives in mind – for example, maximising revenues for the public sector, or with the intention to drive further competition and innovation in the sector, for instance via spectrum caps, set-asides or reserved spectrum for a new entrant (or existing operator). While these are legitimate policy objectives, they may have unintended consequences if they are poorly designed or implemented. For example, when artificially restricting or delaying the amount of spectrum licenced to mobile operators, spectrum prices can be driven up at the expense of the development of the mobile market, leading to lower quality networks and delays in the launch of new technologies.

Few empirical studies have assessed the potential effects of spectrum prices on consumer outcomes. Table 1 summarises the main studies conducted. For example, Kuroda and Baquero (2017), analysing 47 OECD countries over the period 2000–2008, found that spectrum auctions led to lower take-up of 3G. Cambini and Garelli (2017) considered 3G and 4G spectrum assignments in 24 (mostly) developed countries during 2005–2014. They found that spectrum prices and market revenues are positively linked, but the link is not statistically significant once they account for the potential endogeneity by incorporating past lags of spectrum prices as instruments. However, as some recent papers show, the choice of instruments may be problematic as introducing lagged values of both dependent and independent variables does not necessarily address endogeneity or simultaneity bias, despite this being a relatively widespread approach in empirical economics.[1]

While these studies constitute significant positive steps, there are fundamental gaps in the evidence base. No studies have so far considered developing countries, and the broad range of outcomes that matter to mobile consumers. We are also not aware of any study that has looked at the impact of spectrum pricing in the 4G era. Even more importantly, analysing a causal effect requires controlling the direction of the effects. One of the challenges in isolating the impact of spectrum prices on consumer outcomes is that the direction of any impact can work both ways. For example, the expectation of high consumer prices may lead to operators having greater willingness to pay more for spectrum, meaning it is consumer prices driving spectrum prices (rather than the other way around).

Our analysis attempts to address these evidence gaps by developing an econometric model that evaluates the impact of spectrum prices on market outcomes over the period 2010-2017. This study is, to our knowledge, the first to consider the impact of spectrum pricing in the 4G era. We analyse a sample of 229 operators across 64 countries (34 developed and 30 developing) over the period 2010-2017, and consider the impacts of spectrum prices and other policy factors on network coverage, network quality and consumer prices, after isolating the effect of spectrum prices from other confounding factors and controlling for the potential two-way direction of the effects between spectrum prices and consumer outcomes.

TABLE 1

KEY EMPIRICAL STUDIES ANALYSING THE EFFECT OF SPECTRUM PRICES ON CONSUMER OUTCOMES

Paper	Finding	Scope
Cambini and Garelli (2017)	Spectrum availability and spectrum fees are not significantly correlated with mobile industry revenues.	24 countries (mostly developed), 2005-2014
GSMA (2017, 2018)	Link between high spectrum prices and negative outcomes for consumers (higher prices and lower network coverage and quality).	Global - 60 countries, 2000-2016; Europe - 30 countries, 2007-2016; Latin America - 15 countries, 2010-2017; Developing - 102 countries, 2010-2017
Kuroda and Baquero (2017)	Spectrum auctions reduce 3G diffusion rates (take-up is 2-9% lower). When used to raise public revenues, auctions sacrifice consumer surplus.	47 OECD countries, 2000-2008
Madden et al (2014)	Probability of new entry in a market is enhanced by using auction assignments and excess licences.	49 assignments, 1999-2008
Zaber et al (2012)	Spectrum management policies have a significant impact on 3G take-up	126 countries, 2000-2009
Park et al (2011)	No effect of auction or spectrum fees on prices, competition (HHI) or investment.	21 OECD countries, cross-section
Hazlett, Munoz (2009)	The amount of spectrum and degree of market competitiveness are key drivers of retail market outcomes. Auction rules that focus on revenue extraction may conflict with the goal of maximising social welfare.	28 countries, 1999-2003
Gruber (2007)	3G diffusion primarily impacted by market structure and not spectrum assignment method (auctions are not superior to other methods)	17 European countries, cross-section
Bauer (2003)	No relationship between spectrum fees and price of voice	18 countries, cross-section

1. See for example Reed (2014) and Bellmare et al (2015)

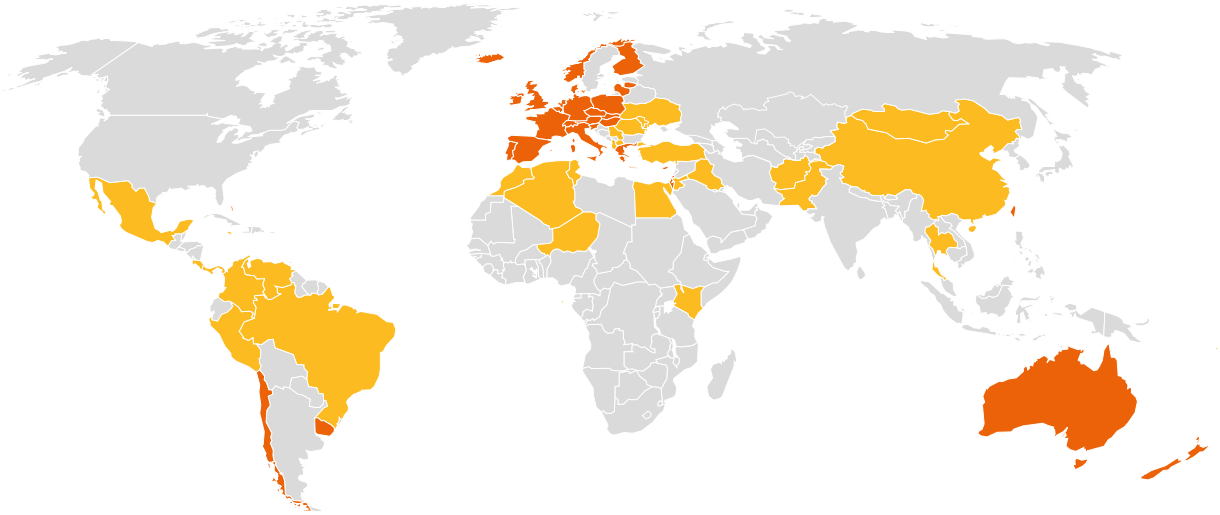
2. Data

2.1 Scope

The analysis in this study covers 229 operators in 64 countries, including 30 developing countries and 34 developed countries, over the period 2010-2017. Countries were categorised by income according to World Bank classifications in 2017, with high-income countries defined as 'developed' and low- and middle-income countries defined as 'developing'.[2] Figure 1 lists the countries included in the study.

FIGURE 1

COUNTRIES IN STUDY



Developing			Developed		
Afghanistan	Jamaica	Panama	Australia	Greece	Poland
Albania	Jordan	Peru	Austria	Hong Kong, SAR China	Portugal
Algeria	Kenya	Romania	Bahamas	Hungary	Singapore
Brazil	Macedonia	São Tomé and Príncipe	Bahrain	Iceland	Slovakia
China	Mexico	Serbia	Belgium	Ireland	Slovenia
Colombia	Moldova	Thailand	Chile	Israel	Spain
Costa Rica	Mongolia	Tunisia	Cyprus	Italy	Switzerland
Egypt	Morocco	Turkey	Czech Republic	Latvia	Taiwan, Province of China
Fiji	Niger	Ukraine	Denmark	Lithuania	UK
Iraq	Pakistan	Venezuela	Finland	Netherlands	Uruguay
			France	New Zealand	
			Germany	Norway	

2. Historical classifications can be found here.

2.2 Spectrum

Data on spectrum indicators was sourced from GSMA Intelligence and included the following:

- new spectrum assignments to operators during the period 2010-2017 (either by auction, beauty contest or other method)
- the price paid by operators for new spectrum assignments
- amount of spectrum assigned per operator
- reserve price (where applicable)
- network coverage and/or quality of service obligations attached to the spectrum licence.[3]

Countries were included in the study if we had a complete set of data on spectrum holdings, assignments and prices during the relevant period (i.e. if we did not have data on one of these three metrics, the country was not included).

In our analysis, we considered two measures of spectrum prices:

1. **Price in (purchasing power parity) dollars** – this is calculated by converting the spectrum price in $PPP and normalising it by the amount of MHz, country population and licence length. It effectively considers the unit price of spectrum on an internationally comparable basis (taking into account the length of spectrum licences, amount of MHz and differences in cost of living). We refer to this as the "$PPP metric".

2. **Spectrum price as a percentage of revenues** – this is calculated as the spectrum licence price as a percentage of operator annual revenues, adjusting for licence duration and the amount of MHz assigned. This metric defines the relative cost of spectrum price from an operator's perspective. We refer to this as the 'CPR metric' (spectrum cost as a proportion of revenue).

While the first metric is currently the standard approach to comparing spectrum pricing across countries, the second metric is particularly important in the context of this study as it gives an indication of the profitability or returns of spectrum payments as an investment.

If high spectrum costs have an impact on a mobile operator's future investment and pricing decisions, this is something that is likely to be better observed by looking at CPR rather than the PPP metric. For example, a spectrum licence can have the same spectrum price of $1 MHz/pop/year in two countries, but this can represent 5% of revenues for an operator in country A and 1% of revenues for an operator in country B. It is clear that for the operator in country B spectrum is less affordable than for the operator in country A.

Therefore, while the $PPP metric is commonly used for benchmarking, it does not provide as much information on how affordable the spectrum is to the operator purchasing the spectrum.

A further advantage of focusing on CPR rather than $PPP is that it allows us to better deal with any potential concerns around endogeneity or reverse causality between spectrum prices and consumer outcomes. By measuring the returns of spectrum as an investment from an operator's perspective, and on the assumption that operators have a required rate of return they need to deliver to investors, our analysis should capture the impact of spectrum prices on consumer outcomes and not conflate it with the impact of consumer outcomes on spectrum prices. If an operator acquires spectrum at a price that is a significant proportion of revenues, this may have a negative impact on consumer outcomes if it means operators reduce (or delay) investment or increase consumer prices. However, there is no obvious reason to think that improved (or worse) consumer outcomes would have a negative (or positive) impact on the rate of return from spectrum investments that operators expect to obtain. This is discussed further in Section 3.4.

Neither the $PPP or CPR metric incorporates annual licence fees due to a lack of comparable data across countries.[4] However, upfront fees are generally the most significant and commonly applied spectrum cost in most countries (and in all countries considered in this study).[5]

3. This information is recorded when it is reported by the regulator or operator. There may be some instances of coverage or quality of service obligations that are imposed but not reflected in the data if the information is not publicly available.
4. The exception to this is China, where operators pay annual fees rather than an upfront cost. As we ultimately amortise the upfront fees into annual payments for our analysis, we were able to include China in the study.
5. Though there are some exceptions, for example in Mexico annual fees represent a significant proportion of total spectrum costs.

2.2.1 Metric calculation

While the spectrum costs captured in our dataset relate to one-off and upfront fees, for the purposes of considering impacts over time it is necessary to convert spectrum costs into recurring costs that can be incorporated in a panel dataset. We do this by amortising the cost of spectrum over the licence length, which is consistent with the financial accounting approach of amortising the cost of an intangible asset over its useful life. Figure 2 provides an illustrative example for both the $PPP and CPR metrics. In this example:

- An operator acquires two spectrum allocations in 2010q3 and 2012q4 and pays lump sums of $1 million and $0.5 million respectively.
- For the first metric, we convert the payment to constant (2016) $PPP prices before normalising by population, amount of MHz acquired and licence duration. This provides the annual unit cost of spectrum. The operator is then assumed to incur this cost until the end of the licence.
- For the second metric, the upfront spectrum payment is amortised over the licence duration to give an annual cost. We then divide this cost by the operator's annual revenues and normalise by the amount of MHz acquired. This provides the cost of a unit of spectrum as a percentage of annual revenues.

FIGURE 2

ILLUSTRATIVE EXAMPLE OF TWO SPECTRUM PRICING METRICS

Time period	Spectrum payment (local currency)	(1) Currency value ($PPP/MHz/pop/year)	(2) CPR
2010q1	0	0	0
2010q2	0	0	0
2010q3	1,000,000	10	1%
2010q4	0	10	1%
2011q1	0	10	1%
2012q2	0	10	1%
2012q3	0	10	1%
2012q4	500,000	15	1.5%
2013q1	0	15	1.5%
2013q2	0	15	1.5%
2013q3	0	15	1.5%
...	0	15	1.5%
2017q4	0	15	1.5%

As a robustness check, we also estimated the annuitised cost of spectrum, which amortises the one-off cost but incorporates the cost of capital. While this requires certain simplifying assumptions to generate a weighted average cost of capital (WACC)[6], the results of our analysis did not materially change so we applied the more simplified linear amortisation approach.

We also constructed an alternative CPR metric that considered the cost of spectrum as a percentage of future operator revenues. This has the advantage of explicitly taking into account the affordability of spectrum costs over the lifespan of the investment. In some developing countries, future revenue growth expectations were high over the 2010-2017 period, meaning it may be important to take those into account when trying to understand the relative affordability of investments made by mobile operators (as spectrum prices are partly determined by expected future revenues).

6. WACCs are calculated at country level due to limited data availability at the operator level.

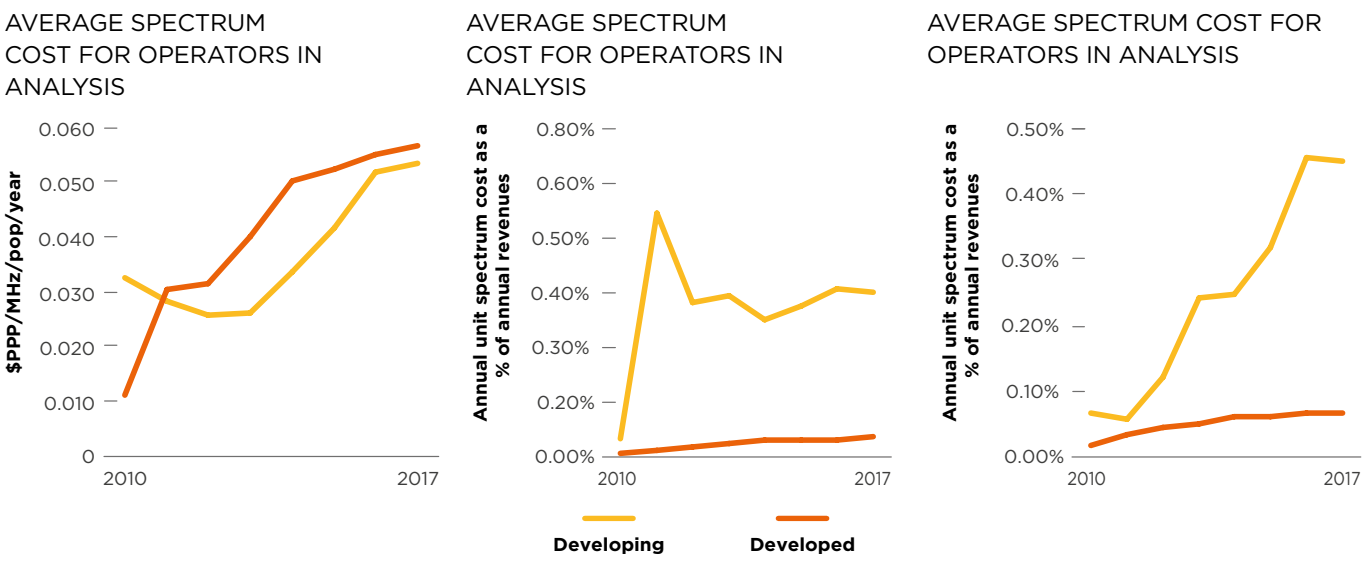
The disadvantage of using future revenues is that it involves developing a metric not solely based on actual (historic) data, as we have to build in forecasts. Market and operator revenue forecasts are available for the period to 2027 from GSMA Intelligence and we incorporate those to build the metric. This introduces forecast rather than actual revenue data into the metric when compared to spectrum prices as a percentage of current revenue, though it serves our purpose to carry out the analysis with an alternative metric that captures future market revenues expectations (rather than current revenues).

To construct affordability as a proportion of future revenues, we calculate the present value of operator revenues for 10 years following spectrum acquisition (discounting using the relevant country's WACC at the time of acquisition[7]). This allows us to calculate an equivalent annual annuity (EAA). We normalise the spectrum assignment to a 10-year licence period[8] and calculate the annual annuity value of the upfront price paid by the operator (again using the country WACC). This is then divided by the revenue EAA to give a recurring CPR metric that considers expected future revenues.

Figure 3 presents trends in the $PPP metric as well as the CPR metric using both current and future revenues. For most of the period, operators in developed countries incurred higher spectrum payments in $PPP terms, but the gap with developing countries closed towards the end of the period.[9] However, when we look at the cost of spectrum as a proportion of current revenues, affordability in developed countries was, on average, around 10 times higher than in developing countries over 2010-2017. When we look at trends taking into account future revenues, the cost is lower (as one would expect if revenues are forecast to grow). Nevertheless, even based on this metric, affordability over the period of analysis was around six times higher in developing countries.

FIGURE 3

TRENDS IN SPECTRUM PRICING METRICS



Source: GSMA Intelligence. We exclude '0' prices from the averages as they are not included in our analysis (this is why averages fall in some years). As spectrum costs are amortised and aggregated for each operator over the period, the charts differ from those presented in the main paper where we present trends in one-off spectrum prices. This analysis is also carried out at the operator-level, whereas the charts in the main paper were produced using moving averages by country.

7. Data on costs of capital by country were sourced from Damodaran online. Historic and forecast revenue data by operator were sourced from GSMA Intelligence.
8. We normalise to a 10-year licence length to avoid forecasting or extrapolating operator revenues past 2027, which would introduce further uncertainty and subjectivity into the calculation.
9. This is consistent with analysis presented in Spectrum Pricing in Developing Countries, GSMA, 2018, and in the main paper.

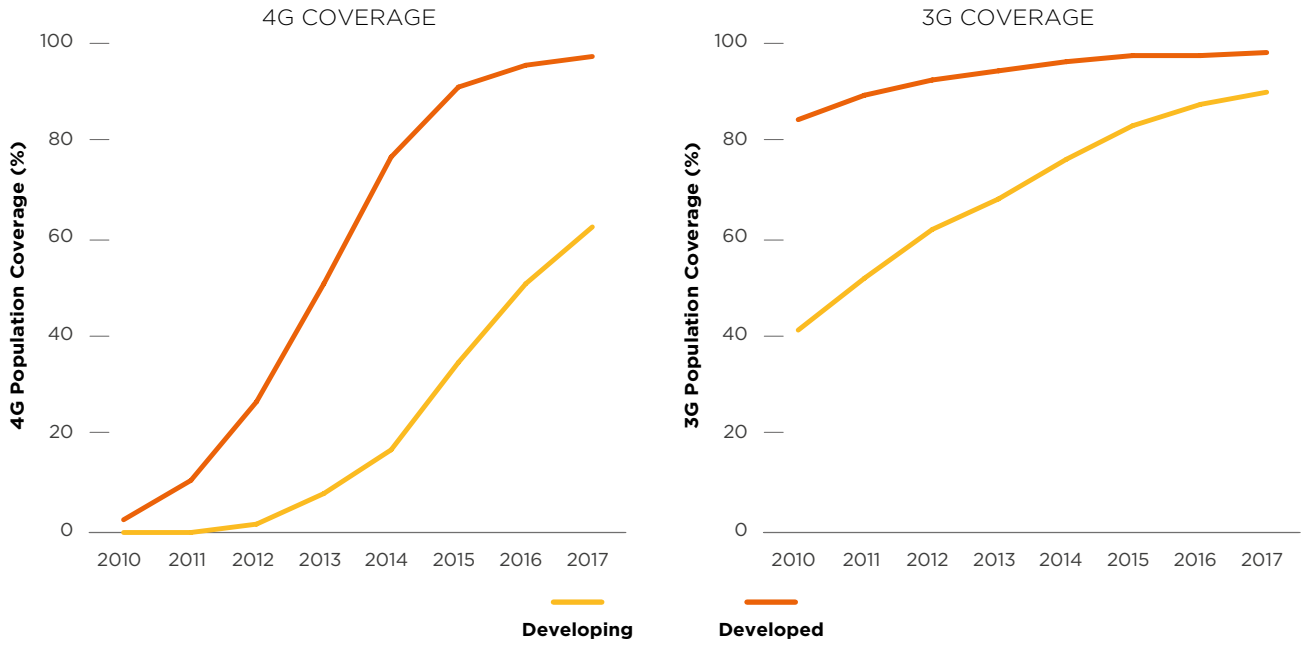
2.3 Network coverage

Data on network coverage is sourced from GSMA Intelligence and measures the proportion of the population resident in an area where 3G or 4G networks are available (i.e. coverage by population rather than by geographic area). The data is gathered from operators and regulators. Where coverage is not reported in each quarter, data is estimated by GSMA Intelligence modelling.[10]

Figure 4 presents average 4G and 3G coverage trends for the countries included in the study. Both developed and developing countries experienced 4G network rollouts during the period of analysis. In the case of many developed countries, our 4G analysis almost covers an entire technology cycle. By contrast, most developed countries already had high levels of 3G coverage in 2010. However, many developing countries launched 3G networks later and so more growth is observed between 2010 and 2017. Given the limited variability in most developed countries, we focus on developing countries when considering 3G coverage.

FIGURE 4

4G AND 3G COVERAGE TRENDS



Source: GSMA Intelligence. Trends reflect the average coverage levels for developing and developed countries included in the study.

10. Further information on GSMA Intelligence data and modelling can be found here.

2.4 Network quality

Network quality consists of several dimensions. Figure 5 sets out a non-comprehensive list.

FIGURE 5

INDICATORS FOR NETWORK QUALITY

Metric	Importance to consumers
Download speeds	Higher download speeds allow consumers to download content more quickly and use data-intensive applications and content, such as video. For example online video streaming with HD quality requires download speeds of 5-10 Mbps.
Upload speeds	Higher upload speeds allow consumers to share more content and enable better performance for services such as online gaming.
Latency	Lower latencies substantially improve the quality of services that require short delays such as online gaming, video calls and VoIP. For example VoIP usually requires latencies of less than 400 milliseconds if a user wishes to have a quality equivalent to traditional fixed telephone services.
Signal strength	Poor (or no) signal strength means that consumer access to mobile services (voice, SMS and data) is slowed or restricted.
Call reliability	If consumers suffer from dropped or blocked calls, they are unable to use voice services as they need.

This study analyses download speeds, upload speeds and latencies for 3G, 4G and across all technologies (2G, 3G and 4G). Data is sourced from Ookla, using the Speedtest® consumer-initiated testing platform that allows mobile users to initiate a 'speed test' to measure network performance at any given time.[11] Each time a user runs a test, they receive a measurement for download speed, upload speed and latency. The test also records the consumer's location, the network operator and the technology being used at the time of the test. Each year, Speedtest is used by 500 million unique users globally, and an average of 10 million consumer-initiated performance tests are run per day.

Using these test results, Ookla calculates the average (mean[12]) network performance metric across all users in each quarter at both the country and operator level. Having a large number of test results on which the average metrics are based is important when measuring network performance because the latter is affected by many factors, including handset, the structure of the consumer's tariff plan (speeds are sometimes throttled), time of day, location, being indoors/outdoors, the weather etc. If the number of tests in a given time period is small, they are likely to be skewed by one or more of these factors. This makes it difficult to compare performance across countries and operators.

If the number of tests is large enough across operators and countries, such factors are more likely to average out, reducing the likelihood of systemic bias. This is a key consideration when using consumer-initiated performance test data because the latter may not represent the 'average' consumer if, for example, users of network performance applications tend to be more technologically sophisticated or if they are more likely to run it when signal is poor (or vice versa). However, so long as there are no differences across countries (e.g. if most users in all countries are similarly advanced in their use of technology), the data can be used to compare network performance. We are not aware of any evidence to suggest that there are systemic biases across countries in this regard.[13]

Figure 6 presents the median and mean test numbers at the operator level in the fourth quarter of each year for which we have data. It shows that the mean number of tests is greater than 10,000 in most quarters (the number of 4G tests is more limited in the early period due to low take-up and limited network rollout).

We therefore consider that the number of tests is sufficient for network performance metrics to be reliable. We also note that many mobile operators use Ookla's data when advertising their network quality and benchmarking themselves against their competitors, providing reassurance around the quality of the data.

11. https://www.speedtest.net/apps/mobile
12. Other measures are calculated such as the median and trimmed mean, but in practice the choice of the 'average' measure does not impact the results.
13. For further information on the Speedtest methodology, see https://www.speedtest.net/insights/blog/testing-methods-sampling/

FIGURE 6

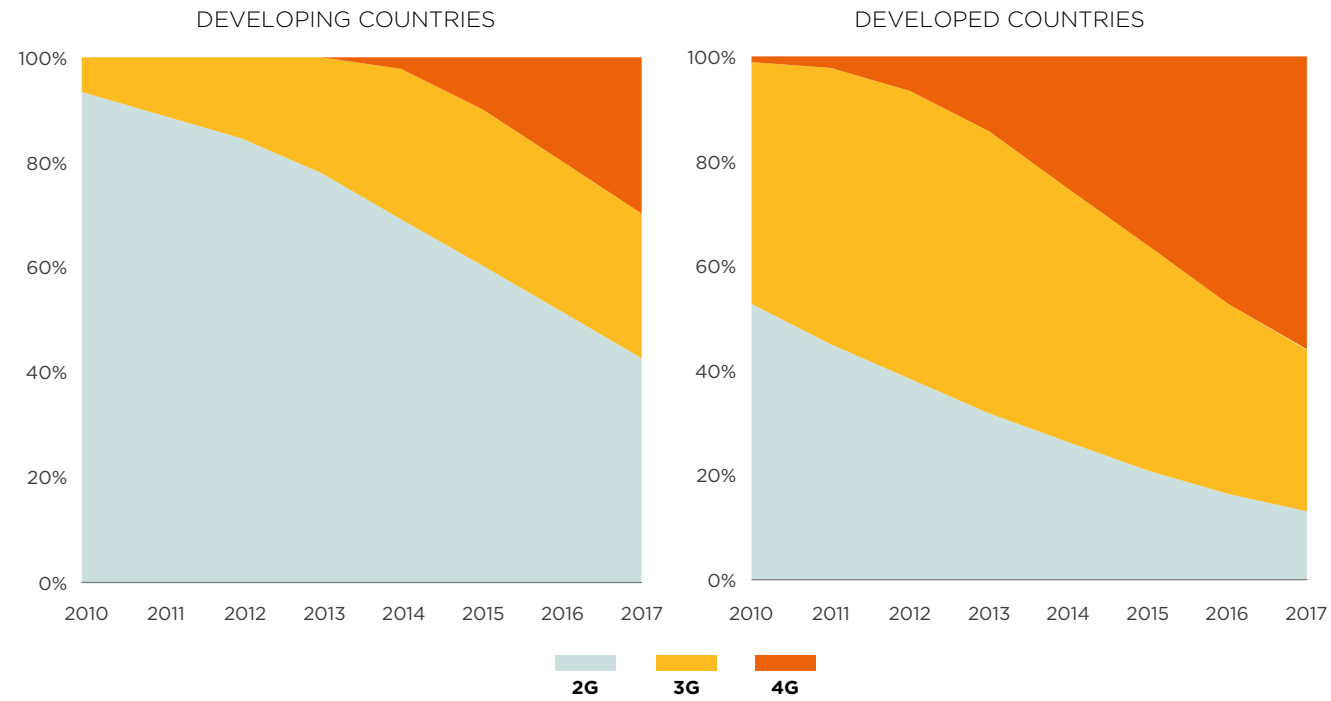
NUMBER OF SPEED TESTS AT THE OPERATOR LEVEL

Time	All tests		3G		4G	
	Mean	Median	Mean	Median	Mean	Median
2011q4	13,659	4,114	13,644	4,077	107	24
2012q4	30,272	10,235	26,554	8,627	5,113	725
2013q4	44,952	16,243	30,907	10,080	19,533	4,182
2014q4	78,633	20,165	26,903	7,306	61,932	14,404
2015q4	71,564	20,962	14,548	4,422	58,934	16,742
2016q4	89,710	24,279	9,406	3,192	84,751	21,014
2017q4	122,764	31,301	7,200	1,906	118,123	28,344

While 4G was the latest technology being rolled out in 2010-2017, Figure 7 shows that 2G and 3G were the predominant technologies in developing countries. Even in developed countries, it was not until the end of the period that 4G became more prevalent than 2G and 3G. From a consumer perspective, the network quality experience on non-4G networks was therefore of considerable importance.

FIGURE 7

MOBILE CONNECTIONS BY TECHNOLOGY



Source: GSMA Intelligence.

2.5 Pricing

Figure 8 sets out the three main ways prices can be measured for mobile services, along with the some of the advantages and disadvantages of each metric.

FIGURE 8

MEASURES OF MOBILE PRICES

Price metric	Description	Pros	Cons
Revenue per unit	Divide operator revenues by subscribers (or voice revenues by call minutes or data revenues by data traffic).	• Relatively easy to source data and calculate.	• Metric is affected by prices and usage. • Does not capture prices actually paid by consumers.
Basket approach	Define one or more baskets representative of consumer usage and calculate the cost of consumption.	• Gives a better indication of what consumers actually pay for mobile services. • Can fix baskets to ensure only price changes are taken into account	• Difficult to identify baskets that are representative for majority of consumers. • Fixed baskets are not representative over time. • Changing baskets over time means price changes are also affected by usage.
Unit prices	Estimate the price paid for voice, SMS and data and divide by usage.	• Controls for changes in quantity consumed.	• Difficult to estimate as voice, SMS and data are bundled together.

For the period 2010-2017 and for the countries included in the study, the only metric available to perform pricing analysis at the operator level is average (recurring) revenue per user (ARPU). This has limitations as a proxy for consumer prices, as it does not measure effectively changes to tariffs and plans currently being offered by mobile operators and can include other sources of revenue such as handsets and value-added services.

We therefore also carry out analysis using ITU pricing data based on two consumption baskets[14]:

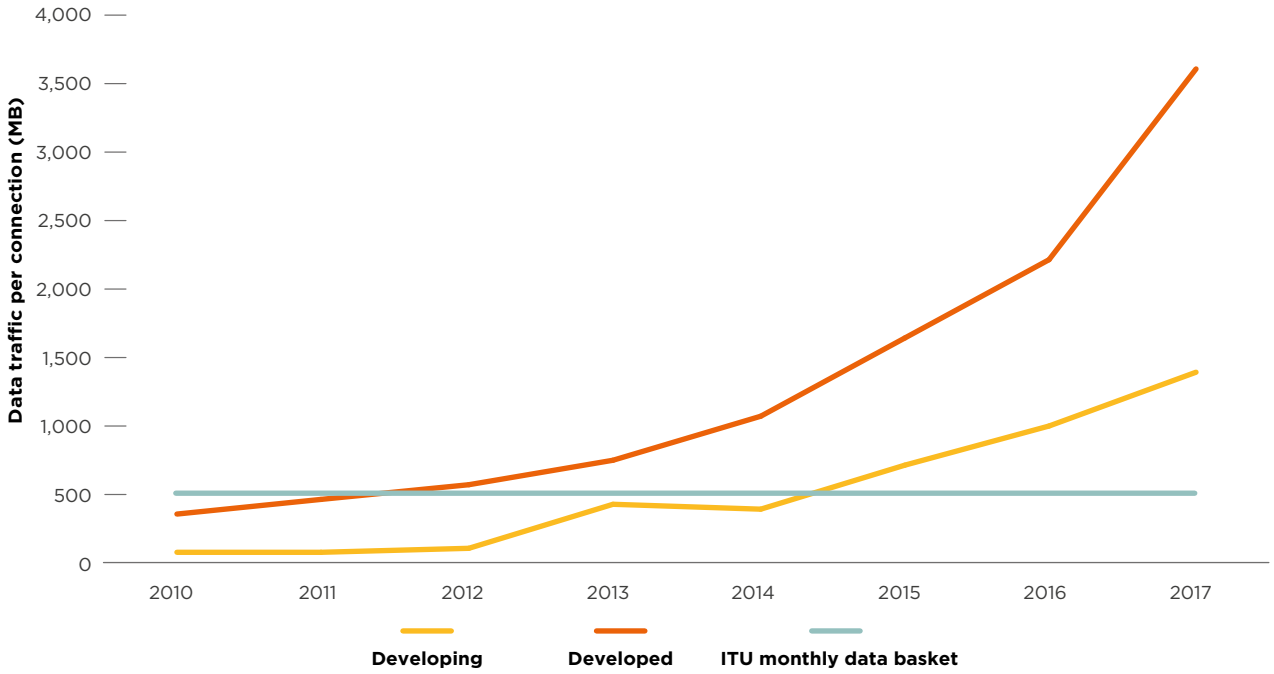
- a 'mobile-cellular sub-basket' or 'voice basket' of 30 outgoing calls per month and 100 SMS messages
- a 'mobile broadband basket' of 500 MB per month (based on prepaid tariffs).

While baskets are more reflective of changes to tariffs being offered to users than ARPU, the assumed usage levels in these particular baskets are unlikely to be reflective of actual consumption patterns for much of the 2010-2017 period, especially in developed countries. Figure 9 shows how average data usage per SIM has evolved in developing and developed countries. While these averages tend to be skewed by large data users, the analysis still shows that for most of the period average data traffic per SIM was more than 500 MB in developed countries, growing to more than 3 GB in 2017. On the other hand, usage has been closer to 500 MB in developing countries, with average monthly data traffic only climbing above 1 GB in 2017. While the mobile broadband basket is a decent approximation to average consumption patterns in developing countries in the period under consideration, it does not track relevant price levels for average consumption patterns in developed countries.

14. For further details, see Annex 1 of Measuring the Information Society Report: Volumes 1, ITU, 2018

FIGURE 9

AVERAGE MONTHLY DATA TRAFFIC PER CONNECTION



Source: GSMA Intelligence. Where operators report total data traffic, we divide this by the number of connections they have. Estimates in the chart represent the median values of average monthly data traffic for operators in our study that reported data traffic volumes.

Similarly, the cellular sub-basket (which does not include any mobile internet data allowance and only very low voice and SMS volumes) is not well suited to track average consumption patterns in developed countries as it is based on a "low-usage" customer from a benchmark set in 2009. More recent mobile pricing baskets[15] apply higher voice and SMS volumes when tracking prices for developed countries.

A further limitation for both the unit price and basket-based approach is that they do not capture well changes in quantity and quality of the mobile service. This is an area that will benefit from further research and analysis, to capture more accurate measures of pricing and understand the impact of public policy on consumer welfare in mobile markets.

15. See for example https://www.oecd.org/sti/broadband/price-baskets.htm and https://www.ofcom.org.uk/__data/assets/pdf_file/0032/108896/icmr-2017.pdf

3. Methodology

3.1 General specification

This study explores whether there is a direct and potentially causal link between spectrum prices and consumer outcomes, specifically coverage, network quality and price. Each of these are outcomes that can be impacted if a mobile operator responds to an increase in spectrum charges by scaling back or delaying its investment strategy or by increasing consumer prices. We also consider the impacts of other policy factors on these consumer outcomes.

The general functional form for each of the consumer outcome models is as follows:

$$y_{ict} = \alpha + \gamma_c C_c + \lambda_t T_t + \sum_{i,c,t=1}^{I,C,T} \mu_{ict} X_{ict} + \rho_{ict} P_{ict} + \varepsilon_{ict} \quad \textbf{(1)}$$

where

y_{ict} is an outcome for customers of an operator ***i*** in country ***c*** in quarter ***t***, i.e. 4G coverage, download speeds, upload speeds, latencies, ARPU.

C_c and T_t are country and time fixed effects – they capture any unobserved variation in consumer outcomes that can be attributed to specific characteristics of each country (e.g. geography) and year (e.g. new handsets, changes in technology).

X_{ict} is a set of control variables that predict changes in consumer outcomes. These vary for each consumer outcome but generally include indicators such as income per capita, population density, market concentration (measured by HHI), operator market share and spectrum holdings.

P_{ict} is the spectrum price for operator ***i*** in country ***c*** and quarter ***t***. To generate a spectrum price over time, whenever an operator acquires spectrum, the upfront free is amortised over the length of the licence (see section 2.2).

ε_{ict} is an error term

In order to account for the existence of heteroskedasticity and serial correlation in our models, we use a cluster-robust estimator with clustering at the country level. We also carried out sensitivity checks using clustering at the operator level.

3.2 Additional specifications

As part of the study, we also assessed whether the impact of spectrum prices varies according to income (i.e. for developed and developing countries) and whether it changes over time. The latter is potentially important because the impact of spectrum prices may not materialise for a while, or alternatively the impact could be most significant in the short term:

- If operators pay more for spectrum than they had expected, they may delay investments rather than reducing them entirely, in which case the potential impact could be restricted to the short term (whereas in the long term, the operator 'catches up');
- Alternatively, operators that pay high spectrum prices may still make the initial/short-term investments they had planned after the assignment but reduce their longer term investments, in which case the potential impacts would not materialise until the medium or longer term.

To look at impacts by income, we estimate all specifications for developed and developing countries separately, in addition to modelling all countries together.

To assess whether the impact of spectrum price changes over time, we adjust our specification as follows:

$$y_{ict} = \alpha + \gamma_c C_c + \lambda_t T_t + \sum_{i,c,t=1}^{I,C,T} \mu_{ict} X_{ict} + \rho^{Y1}(P_{ict} * D_{ict}^{Y1}) + \rho^{Y2}(P_{ict} * D_{ict}^{Y2}) + \rho^{Y3+}(P_{ict} * D_{ict}^{Y3+}) + \varepsilon_{ict} \quad \textbf{(2)}$$

where

$D_{ict}^{Y1}, D_{ict}^{Y2}$ and D_{ict}^{Y3} are dummy variables that take values of 1 for operator ***i*** in country ***c*** in quarter ***t*** if an operator has incurred a spectrum licence payment within the previous 1, 2 and 3+ years respectively (0 otherwise).

In addition, we also studied the impact of 'high' or 'excessive' spectrum prices to consider whether material impacts on a mobile operator's ability to invest occur when spectrum prices are particularly 'excessive' and not small variations around average values.

We used three different metrics to capture extremely high spectrum prices. These were: (i) prices that are above the 75th percentile (Outliers); (ii) prices above the inner fence (75th percentile + 1.5*IQR) (Big Outliers); and (iii) prices above the outer fence (75th percentile + 3*IQR) (Extreme Outliers). These were defined for both spectrum pricing metrics ($PPP and CPR metrics) and separately for developed and developing countries.

To assess whether spectrum prices primarily have an impact when they are 'excessive', we adjust our specification as follows:

$$y_{ict} = \alpha + \gamma_c C_c + \lambda_t T_t + \sum_{i,c,t=1}^{I,C,T} \mu_{ict} X_{ict} + \rho_{ict} P_{ict} * E_{ict} + \varepsilon_{ict} \quad \textbf{(3)}$$

where

E_{ict} is a dummy variable that takes a value 1 when the spectrum price for operator i in country c in quarter t is above the threshold used to define excessive prices, i.e. above the 75th percentile, inner fence or outer fence (and 0 otherwise).

3.3 Control variables

To isolate the impact of spectrum pricing on consumer outcomes, it is important to control for other factors that influence the latter, particularly those that are also correlated with spectrum pricing. In addition to country- and time-fixed effects, we control for the following supply- and demand-side factors:

- Rural population – if the proportion of a country's population that lives in rural areas falls over time, this will reduce the costs of rollout and may impact the network quality experienced by consumers.
- Population density – if a country becomes more densely populated, this will reduce the costs of rollout and may impact network quality experienced by consumers. In the model, we apply a logarithm transformation to population density.
- Existing mobile infrastructure (used in coverage models) – if there is a significant 3G network at the start of the 4G rollout, this will reduce costs of deployment for 4G.
- GDP per capita – this is used as a proxy for income. As it increases within a country, consumers may be more willing to take up 4G services, which may drive 4G network rollout. In the model, we apply a logarithm transformation to GDP per capita.

We also control for the following market factors:

- Market concentration (measured using the HHI index)[16] – this is used as a proxy for market structure and the extent of competition within a market. In the model, we apply a logarithm transformation to HHI.
- Operator scale – in addition to market concentration, the scale of an operator can be an important factor that drives consumer outcomes. Greater scale may allow mobile operators to distribute costs across more users and therefore improve the case for investment.
- Smartphone adoption – as more consumers use smartphones, they are likely to develop more digital skills and demand newer technologies and more bandwidth.

Lastly, we control for other spectrum policy factors:

- Spectrum holdings – operators with more spectrum will have more capacity to deliver faster speeds and will require less investment to roll out 3G and 4G networks (other things being equal). We include controls on the amount of 3G and 4G spectrum held by operators.[17]
- Spectrum timings – the timing of spectrum allocation is important for both 3G and 4G coverage. An operator that has had 3G/4G spectrum available to use for more than two years will have had more time to achieve greater network coverage than an operator that has had spectrum for less than one year.
- Coverage obligations – where an operator has acquired a spectrum licence with certain coverage obligations, we capture this using a dummy variable (which takes a value of '1' if the operator has a coverage obligation or zero otherwise).
- Quality of service obligations – we also include a dummy variable capturing whether an operator has a quality-of-service obligation attached to one of its spectrum licences.

Aside from the above, there are two mobile-specific factors that we have not included in our model. First, spectrum holdings would ideally be estimated in separate frequency bands since they have different propagation and capacity properties that may have a bearing on the resulting coverage and network performance. While this approach should improve the precision of estimates, separating spectrum holdings substantially decreases variability in the dataset. We carried out a sensitivity check based on such an approach which showed that the overall results of the analysis did not change in terms of the impact of spectrum pricing on consumer outcomes. However, the lack of variability across and within operators means that the estimated parameters for spectrum variables with separate frequency bands do not appear to be strong predictors of 4G coverage or network quality.

Second, in the case of network quality models, there could be differences in quality across operators driven by network congestion effects. This could be controlled by including the data volumes or number of connections in a 3G or 4G network (more users on a network will mean higher network congestion). However, we do not include these in our main results as it is likely to introduce endogeneity.[18] As a sensitivity check, we ran the models including the connections variables and our findings in terms of the impact of spectrum prices did not change.

16. This is a measure of market concentration commonly used in competition analysis. It is calculated by squaring the market shares of the operators in a market and summing the resulting numbers.
17. Given the different properties of the spectrum bands, in particular the fact that sub-1 GHz spectrum is better suited for achieving wide coverage, and spectrum above 1 GHz is better suited to high capacity rates, it would be preferable to have separate spectrum variables by band. However, as our base model is a fixed effects regression, it is driven by variation within each country. Spectrum holdings do not exhibit significant variation at this level – once it is assigned, it does not change unless there is a merger or spectrum is re-auctioned or re-assigned. We therefore aggregate spectrum holdings into '4G' and '3G' bands to increase the variability of the data.
18. There may be simultaneity between data consumption or connections and network quality in that, while connections may drive network quality through network congestion, an increase in connections on a given technology may also be due to better network quality.

3.4 Addressing endogeneity

One of the challenges in isolating the impact of spectrum prices on consumer outcomes is that the direction of impact can work both ways. For example, the existence or expectation of high consumer prices may lead to operators having greater willingness to pay for more spectrum, meaning it is consumer prices driving spectrum prices (rather than the other way around).

A similar issue also applies to coverage and network quality. An operator may be willing to pay a high spectrum price in the expectation that they will achieve wide network coverage and/or improved network quality. On the other hand, if the operator pays more than it expected then this could reduce investment, which would have a negative impact on network quality. As the two mechanisms work in difference directions, the specifications outlined above will not be sufficient to infer the impact of spectrum prices on consumer outcomes.

To address the 'reverse causality' problem, we adopt a two-fold strategy. The first is to use the CPR metric for spectrum price. If an operator acquires spectrum at a price that is a significant proportion of revenues, this may have a negative impact on consumer outcomes if it means operators reduce (or delay) investment or increase consumer prices. However, there is no logical reason to think that improved (or worse) consumer outcomes would have a negative (or positive) impact on the affordability of acquiring a spectrum licence when considering the latter as a percentage of operator revenue.

The second strategy is to use instrumental variable regression with the $PPP metric. This requires the identification of one or more indicators that impact the price of spectrum but not the consumer outcomes. In this study, we used the following instruments:

(i) Central government debt maturing in 12 months or less (as a % of GDP). In a previous study[19], GSMA found that developing countries with high levels of public indebtedness tend to have higher spectrum prices (though the correlation is not as strong in developed countries). Given that spectrum prices are unlikely to determine government debt, the more plausible interpretation is that governments in developing countries experiencing financial challenges are using spectrum assignments to increase public sector revenues.

(ii) A dummy variable that captures whether the spectrum was assigned using a non-auction method. Auctions are likely to result in higher spectrum prices than other assignment methods because they allow the market to determine the price (subject to format and design decisions). However, we would not expect existing (or future) consumer prices of network coverage/quality levels to be a factor in determining whether the government assigned spectrum using an auction or not.

(iii) Average spectrum prices in the surrounding region. The rationale for this instrument is that regulators often use spectrum prices in surrounding countries or countries in the same region as benchmarks to inform their own reserve prices or the price of spectrum itself. However, one would not expect prices or coverage in a country to inform spectrum prices in surrounding countries.[20]

(iv) Average reserve prices in the surrounding region. Similar to the second instrument, regulators may use reserve prices set by countries in the same region as benchmarks when setting their own reserve or spectrum prices. We also considered using reserve prices within countries but there is risk that this is not exogenous as regulators may consider current and projected prices (and/or coverage and network quality levels) in the country when setting reserve prices.

We used the first instrument to assess the impact of spectrum prices in developing countries, as there is a much stronger link between short-term government debt and spectrum prices (in $PPP) in developing countries than developed countries. We used the other three instruments for developed countries, as they were not as strong for developing countries. When we analyse all countries together, we utilise all four instruments. While we present these results for completeness, given the differences in market dynamics and characteristics between developed and developing countries, we give most weight to the specifications by development classification.

Instrumental variable regressions were run using the 2SLS estimator; for 'all' and developed countries we also checked the results using the GMM estimator; the overall findings did not materially change.

Another method to address the endogeneity of one or more regressors is to implement a dynamic panel data model, for example the Arellano and Bond[21] or Blundell and Bond[22] estimators. These are designed for models where the lagged dependent variable is included and some of the regressors are endogenous. Under these estimators, the endogenous regressors can be instrumented using 'internal instruments' (lags of the endogenous variables, including the lagged dependent variable) as well as 'external instruments' (variables that are exogenous to the main model).

19. Spectrum Pricing in Developing Countries, GSMA, 2018
20. The use of 'regional' instruments has been used in other papers, for example Briglauer, Cambini and Grajek, Speeding Up the Internet: Regulation and Investment in European Fiber Optic Infrastructure (2017).
21. https://academic.oup.com/restud/article-abstract/58/2/277/1563354?redirectedFrom=fulltex
22. https://www.ucl.ac.uk/~uctp39a/Blundell-Bond-1998.pdf

While we considered implementing dynamic panel models as a third strategy to address the endogeneity bias in our specification, it is unlikely that past values of spectrum price are uncorrelated with consumer outcomes during the period of our analysis. Given that operators consider future prices, revenues and coverage levels when considering how much to bid for spectrum (or whether they are willing to purchase it at a given price), it is unrealistic to assume that spectrum prices are exogenous with respect to consumer outcomes one or two (even three or four) years after the acquisition. We therefore give more weight to econometric methods that only use external instruments. Furthermore, for the majority of the consumer outcomes considered in the study, there is no clear conceptual rationale to estimate a dynamic panel model, which is typically used to allow for a partial adjustment mechanism in the dependent variable.

The one possible exception is consumer price, which may require a partial adjustment and therefore a dependent variable lag. One might also expect operators to use past prices to inform or determine prices in the current period. We therefore implement an Arellano Bond estimator when assessing the impact of spectrum pricing on consumer prices, incorporating both internal instruments and the external instruments discussed above (central government debt for developing countries and assignment method and spectrum prices and reserve prices in the surrounding region for developed countries).

3.5 Robustness checks

In addition to the general specifications outlined above, we implemented a number of robustness checks. These included the following:

- Cluster standard errors at the operator level
- MNO fixed effects model – there may be unobservable factors that need to be controlled with regards to operators within each country. For instance, it may be the case that operators differ in terms of business strategies, resources, firm structure, size and management. These factors may have an effect on the degree of innovation and/or network quality of each operator
- Non-linear functional forms – we apply the general specification but with logarithmic transformations to the dependent variables (with the exception of consumer price outcomes as these are log-transformed already). In the case of 3G and 4G coverage, we apply a logit transformation as this is more appropriate for indicators that are bounded between 0 and 1 (as the dependent variable is a proportion of total population).
- With regards to specifications that use the CPR metric, we do a robustness check where CPR is calculated using future revenues rather than current revenues (using the approach set out in Section 2.2).

3.6 Identifying robust findings

To determine whether spectrum prices have a significant impact on consumer outcomes, it is important that results hold to a number of robustness and sensitivity checks, particularly given some of the underlying assumptions in each of the models. We therefore developed a criteria to assess the robustness of our findings.

We consider findings to be compelling and robust if we observe statistically significant findings in the majority of CPR models *AND* in our instrumental variable regression for the $PPP metric.

If we observe statistically significant findings in either the CPR model or the $PPP model but not both, we conclude that there is evidence that spectrum pricing has an impact on that particular consumer outcome but it is not definitive.

If we do not find any statistically significant findings, then we conclude that spectrum price has no significant impact on the consumer outcome. If the results are inconsistent across different methods and robustness checks, the impact is considered inconclusive.

4. Results

4.1 4G networks

4.1.1 4G coverage

Figures 10a and 10b present results for the general specification using the CPR metric and the instrumental variable regression using the $PPP metric respectively. We present the coefficients of primary interest (spectrum price, spectrum holdings and the time since spectrum has been allocated). Full regression outputs are provided in Annex 1.

Results are estimated for all countries and for developing and developed countries separately – though, as discussed in Section 3, we mostly rely on the two income-specific specifications when interpreting the results given the different context and market dynamics. Indeed, Figure 10a shows that the results for 'all countries' are much more similar to those for developing countries, suggesting that the latter is driving the overall results. It is therefore preferable to consider the results for developing and developed countries separately.

Figure 10a shows that there is a negative relationship between spectrum price (measured by CPR) and 4G coverage, notably in developing countries where a 1 percentage point increase in CPR drives a 4.8 percentage point reduction in 4G coverage. This impact is sustained both in the short and medium term (first and second years after acquiring spectrum) as well as the long term (more than two years after acquisition), when a 1ppt increase in CPR drives a 6.1pp reduction in 4G coverage. There is also a negative relationship in developed countries, though this appears to be primarily driven by an impact the first year after the spectrum assignment, indicating that high spectrum cost can delay investment in the short term.[23]

The robustness checks on the CPR metric, presented in Annex 1, show that the negative impacts observed in developing countries are statistically significant across all alternative specifications, while in developed countries the first-year impact is robust to three out of four robustness checks (the exception is the model using operator fixed effects).

The (second-stage regression) results in Figure 10b also show that once the endogeneity of the $PPP metric is addressed using instruments, higher spectrum prices again have a negative impact in both developing and developed countries. As a logarithmic transformation has been applied to the $PPP metric, the results suggest that a 1% increase in spectrum cost drives a 0.53pp reduction in 4G coverage in developing countries and a 0.16pp reduction in developed countries.[24]

Full regression outputs for the instrumental variable analysis are provided in Annex 1, including the results of the first-stage regression which show that the instruments operate in the expected direction – in developing countries, increased short-term government debt is linked to higher spectrum prices while in developed countries, non-auction assignments and higher spectrum prices in the region are linked to lower and higher spectrum prices respectively. Further details on diagnostics, including tests for under-identification, weak identification and (where we have more than one instrument for 'all' and developed countries) over-identification are also provided in Annex 1. For 4G coverage, the instruments do not appear to be weakly identified and for developed countries they appear valid.

Bringing all the results together, we conclude that in both developing and developed countries there is strong and compelling evidence that high spectrum prices had a consistently negative and statistically significant impact on 4G coverage. In developed countries, this impact appears to be particularly strong in the short term while in developing countries it was persistent over time.

The results also highlight other important findings related to spectrum and public policy. First they show that early allocation of 4G spectrum holdings has a positive and statistically significant effect on 4G network coverage. A delay of at least two years in releasing spectrum results in an average reduction in 4G coverage of 11-16 percentage points.[25]

23. The CPR coefficients are much larger for developed countries because overall CPR was much lower (as shown in Figure 3). Therefore, while a 1 percentage point increase in the cost of spectrum as a proportion of revenues drives reduction in 4G coverage of 86.34 percentage points according to the results, such a change is an order of magnitude above what we observe in developed countries (where the average cost of spectrum was 0.04% of current revenues during the 2010-2017 period).

24. As we apply a logarithmic transformation on the $PPP metric but not the dependent variable, the coefficient can be interpreted as follows: a 1% increase in spectrum cost is linked to a change in (β/100) units of the dependent variable – in this case the percentage of a country's population covered by 4G networks. As the coefficient refers to the impact of a 1% increase in spectrum cost, it cannot be directly compared to the coefficient in the CPR regression, which refers to the impact of a 1 percentage point increase in the cost of spectrum as a percentage of revenues.

25. The variable "4G spectrum: 2+ years" is a dummy variable that takes a value of 1 when an operator has held 4G spectrum for two years or longer. The reference baseline is when an operator has had spectrum for less than one year.

We also find evidence that the amount of 4G spectrum licensed to operators has a significant impact on 4G coverage, with an additional 1 MHz of spectrum driving a 0.1-0.2 percentage point increase in 4G coverage.[26] Therefore, an additional allocation of 20 MHz (which is the median amount of spectrum obtained per assignment in our sample) to an operator would, on average, increase 4G coverage by 2-4 percentage points.

FIGURE 10A

OLS REGRESSION RESULTS USING CPR

	4G coverage (percentage of population)					
	All countries		Developing		Developed	
	(1)	(2)	(3)	(4)	(5)	(6)
Spectrum price						
Average effect	-4.746***		-4.793***		-86.34*	
Impact in first year		-3.423***		-3.595***		-72.53**
Impact in second year		-3.750***		-3.958**		-65.78
Impact after two years		-6.228**		-6.075**		-62.85
Spectrum policy						
4G spectrum holdings	0.106***	0.105***	0.0876	0.0818	0.0982***	0.0999***
4G spectrum: 1-2 years	9.539***	9.654***	9.603***	9.717***	7.897**	7.835**
4G spectrum: 2+ years	15.56***	15.97***	11.63***	12.30***	14.93***	14.75***

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

Coefficients represent results of second-stage regressions. Full regression outputs are presented in Annex 1.

FIGURE 10B

INSTRUMENTAL VARIABLE REGRESSION RESULTS USING LOG OF $PPP/MHZ/POP/LICENCE YEAR

	4G coverage (percentage of population)		
	All countries	Developing	Developed
Spectrum price			
Average effect	-5.723*	-53.46**	-16.40***
Spectrum policy			
4G Spectrum holdings	0.135***	0.117	0.159***
4G spectrum: 1-2 years	8.793***	8.784**	5.902***
4G spectrum: 2+ years	14.60***	12.90***	14.37***

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

Coefficients represent results of second-stage regressions. Full regression outputs are presented in Annex 1.

26. The coefficients on spectrum holdings are not statistically significant in developing countries in this particular specification, though they do appear as significant in alternative models (see Annex 1).

4.1.2 4G download speeds

Figures 11a and 11b present results using the same approach as for 4G coverage, with full regression outputs again presented in Annex 1. The CPR results suggest that higher spectrum costs drove a reduction in 4G download speeds in the long term (after two years) in developed countries, with a 1pp (or 0.1pp) increase in CPR linked to a reduction in 4G download speeds of 23.8 Mbps (or 2.38 Mbps). This finding is robust to two out of four robustness checks of the CPR model (see Annex 1). We do not observe any impacts in developing countries.

The IV results of the $PPP metric, presented in Figure 11b, provides further evidence that spectrum price had a negative impact of 4G download speeds in developed countries, with a 1% increase in spectrum cost linked to a reduction in 4G download speeds of 0.07 Mbps.[27, 28] We do not find a negative impact in developing countries – in fact, the coefficient on spectrum price is positive and significant at the 10% level.

Taking the results in the round, in developing countries we conclude that the impact of spectrum pricing on 4G download speeds is negligible or otherwise inconclusive, given the different results using CPR and PPP metrics. However, in developed countries there is strong evidence that higher spectrum prices drove lower 4G download speeds, particularly in the long term.

In terms of other policy factors, the amount of 4G spectrum held by operators has a positive impact in developed countries in the IV regression, though the impact is statistically insignificant in the CPR results.

FIGURE 11A

OLS REGRESSION RESULTS USING CPR

4G download speeds (Mbps)

	All countries		Developing		Developed	
	(1)	(2)	(3)	(4)	(5)	(6)
Spectrum price						
Average effect	-0.0218		-0.212		-14.69	
Impact in first year		0.167		-0.164		-0.0466
Impact in second year		-0.434		-0.418		-24.71
Impact after two years		0.182		-0.0184		-23.80*
Spectrum policy						
4G spectrum holdings	0.0238	0.0239	0.00192	0.00201	0.0311	0.0330

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

Full regression outputs (including other controls) are presented in Annex 1.

FIGURE 11B

INSTRUMENTAL VARIABLE REGRESSION RESULTS USING LOG OF $PPP/MHZ/POP/LICENCE YEAR

4G download speeds (Mbps)

	All countries	Developing	Developed
Spectrum price			
Average effect	-5.977***	7.074*	-7.475***
Spectrum policy			
4G Spectrum holdings	0.0398***	-0.0199	0.0394***

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

Coefficients represent results of second-stage regressions. Full regression outputs are presented in Annex 1.

27. As we apply a logarithmic transformation on the $PPP metric but not the dependent variable, the coefficient can be interpreted as follows: a 1% increase in spectrum cost is linked to a change in (β/100) units of the dependent variable – in this case Mbps.
28. As in the case of 4G coverage, the results of the diagnostic tests in Annex 1 suggest that the instruments are both valid and not under- or weakly identified.

4.1.3 4G upload speeds

Figures 12a and 12b present results for 4G upload speeds. The CPR results show that higher spectrum prices had a negative impact in developing countries, particularly two years after the purchase, but not in developed countries. The results for the former are robust to three out of four alternative specifications (see Annex 1). On the other hand, the IV results show no statistically significant impact in developing countries but that there may have been negative impacts in developed countries, with a 1% increase in the PPP cost associated with a reduction in 4G upload speeds of 0.066 Mbps.

We therefore conclude there is some evidence to suggest that higher spectrum prices drove reductions in 4G upload speeds in both developed and developing countries.

In terms of other policy factors, we do not observe any statistically significant impacts with regard to 4G spectrum holdings in the CPR analysis, but the IV results suggest a positive impact in developed countries.

FIGURE 12A

OLS REGRESSION RESULTS USING CPR

4G upload speeds (Mbps)

	All countries		Developing		Developed	
	(1)	(2)	(3)	(4)	(5)	(6)
Spectrum price						
Average effect	-0.438**		-0.536**		-0.544	
Impact in first year		-0.247		-0.368*		0.741
Impact in second year		-0.172		-0.219		-1.505
Impact after two years		-0.698***		-0.816***		-1.543
Spectrum policy						
4G spectrum holdings	0.00480	0.00468	-0.00455	-0.00494	0.00565	0.00579

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

Full regression outputs (including other controls) are presented in Annex 1.

FIGURE 12B

INSTRUMENTAL VARIABLE REGRESSION RESULTS USING LOG OF $PPP/MHZ/POP/LICENCE YEAR

4G upload speeds (Mbps)

	All countries	Developing	Developed
Spectrum price			
Average effect	-3.872***	1.589	-6.618***
Spectrum policy			
4G Spectrum holdings	0.0135***	-0.0107	0.0120***

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

Coefficients represent results of second-stage regressions. Full regression outputs are presented in Annex 1.

4.1.4 4G latencies

Figures 13a and 13b present results for 4G latencies for the CPR and PPP metric respectively. There is limited evidence of spectrum pricing having any impact, with no statistically significant results in almost all OLS and IV regressions.

FIGURE 13A

OLS REGRESSION RESULTS USING CPR

4G latencies (ms)

	All countries		Developing		Developed	
	(1)	(2)	(3)	(4)	(5)	(6)
Spectrum price						
Average effect	0.0148		0.847		-11.12	
Impact in first year		-1.572*		-0.880		-0.334
Impact in second year		0.0222		0.736		-12.58
Impact after two years		0.841		1.869		-13.68
Spectrum policy						
4G spectrum holdings	-0.00429	-0.00390	0.0274	0.0281	0.00328	0.00407

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

Full regression outputs (including other controls) are presented in Annex 1.

FIGURE 13B

INSTRUMENTAL VARIABLE REGRESSION RESULTS USING LOG OF $PPP/MHZ/POP/LICENCE YEAR

4G latencies (ms)

	All countries	Developing	Developed
Spectrum price			
Average effect	-0.831	-9.988	-5.398
Spectrum policy			
4G Spectrum holdings	-0.0163	0.0550	0.00175

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

Coefficients represent results of second-stage regressions. Full regression outputs are presented in Annex 1.

4.2 3G networks

4.2.1 3G coverage

Figures 14a and 14b present results for 3G coverage for developing and 'all' countries, which also includes developed country operators that had coverage levels less than 50% at the start of the period in 2010 (this ensures we only include operators with variation in coverage over the period).[29] The results using the CPR metric suggest that spectrum prices had a negative impact on the rollout of 3G networks in developing countries, particularly in the short and medium term, with a 1 percentage-point increase in CPR driving a reduction in 3G coverage of 0.03 percentage points in the first year after a spectrum assignment and 0.13 percentage points in the second year (in the third year, the impact becomes insignificant). The CPR results hold to most robustness checks, with the exception of using operator fixed effects (see Annex 1). When considering the IV approach using the $PPP metric, we do not find a negative impact in developing countries, though we do find a statistically significant and negative impact when considering all countries with a wider set of instruments. The coefficient indicates that a 1% increase in spectrum cost drove a reduction in 3G coverage of 0.05pp.

We therefore conclude that in developing countries there is credible but not conclusive evidence that high spectrum prices had a negative and statistically significant impact on 3G coverage, particularly in the first two years following the purchase of the licence.

Similar to the findings for 4G coverage, the results also highlight the importance of other spectrum policies. Early release of spectrum is again important – an operator that has had spectrum for at least two years longer than another operator achieved average 3G coverage levels more than 20 percentage points higher in developing countries (other factors held constant).

FIGURE 14A

OLS REGRESSION RESULTS USING CPR

3G coverage (percentage of population)

	All countries		Developing	
	(1)	(2)	(3)	(4)
Spectrum price				
Average effect	-0.0447***		-0.0472***	
Impact in first year		-0.0290***		-0.0309***
Impact in second year		-0.123***		-0.128***
Impact after two years		-0.0172		-0.0183
Spectrum policy				
3G spectrum holdings	-0.0108	-0.0109	-0.00422	-0.00427
3G spectrum: 1-2 years	14.04***	14.07***	15.00***	15.03***
3G spectrum: 2+ years	20.28***	20.25***	22.61***	22.57***

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

Full regression outputs (including other controls) are presented in Annex 1.

29. We explored different thresholds on starting coverage such as 40% and 60% as well as restricting the sample to operators that increased coverage by more than 40% between 2010 and 2017. The overall results did not materially change.

FIGURE 14B

INSTRUMENTAL VARIABLE REGRESSION RESULTS USING LOG OF $PPP/MHZ/POP/LICENCE YEAR

	3G coverage (percentage of population)	
	All countries	Developing
Spectrum price		
Average effect	-4.721**	5.023
Spectrum policy		
3G Spectrum holdings	-0.0708***	0.00418
3G spectrum: 1-2 years	13.59***	13.76***
3G spectrum: 2+ years	18.64***	20.51***

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

Coefficients represent results of second-stage regressions. Full results are presented in Annex 1.

4.2.2 3G download speeds

Figures 15a and 15b present results for 3G download speeds. The results for the CPR regressions show that higher spectrum prices had significant negative impacts in both developing and developed countries, with impacts materialising in the medium to longer term after one year. The findings in developing countries are robust to all alternative specifications while in developed countries they are robust to two out of four alternative models (see Annex 1). The IV analysis also supports a negative impact in developing countries. The average effect for developed countries in the IV analysis is not significant.[30]

We therefore interpret the findings that higher spectrum prices have a clear negative impact on 3G download speeds in developing countries, while for developed countries, there is also evidence of a negative impact but it is less conclusive.

In terms of other control variables and policy factors, the amount of 3G spectrum holdings has a positive impact on download speeds in developed countries.

FIGURE 15A

OLS REGRESSION RESULTS USING CPR

	3G download speeds (Mbps)					
	All countries		Developing		Developed	
	(1)	(2)	(3)	(4)	(5)	(6)
Spectrum price						
Average effect	-0.00417***		-0.00382***		-5.247*	
Impact in first year		0.00104		-0.000111		-2.334
Impact in second year		-0.0120***		-0.0109***		-5.732**
Impact after two years		-0.0203***		-0.0135***		-5.049
Spectrum policy						
3G spectrum holdings	0.00861**	0.00857**	0.00433	0.00428	0.00988*	0.0102*

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

Full regression outputs (including other controls) are presented in Annex 1.

30. When we apply the same instruments for the impact of spectrum prices in the second year after purchase in developed countries, we find a negative impact that is consistent with the CPR results (see Annex 1). However, the test for over-identification suggests that the instruments for developed countries may not be valid so we treat these results with caution.

FIGURE 15B

INSTRUMENTAL VARIABLE REGRESSION RESULTS USING LOG OF $PPP/MHZ/POP/LICENCE YEAR

3G download speeds (Mbps)

	All countries	Developing	Developed
Spectrum price			
Average effect	-0.0322	-1.769***	0.0427
Spectrum policy			
3G Spectrum holdings	0.00991***	-0.00295	0.00999***

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

Coefficients represent results of second-stage regressions. Full regression outputs are presented in Annex 1.

4.2.3 3G upload speeds

Figures 16a and 16b present results for 3G upload speeds. The results for the CPR metric show that higher spectrum prices had significant negative impacts in developing countries, with impacts again materialising in the medium-to-longer term after one year (similar to 3G download speeds). The findings are robust to all alternative specifications (see Annex 1). The IV regression results for the PPP metric also show a negative impact in developing countries. On the other hand, while there are negative impacts in developed countries the results are not statistically significant both in the CPR and PPP regressions.

We therefore interpret the findings that higher spectrum prices have a clear negative impact in developing countries, with limited impacts in developed countries.

FIGURE 16A

OLS REGRESSION RESULTS USING CPR

3G upload speeds (Mbps)

	All countries		Developing		Developed	
	(1)	(2)	(3)	(4)	(5)	(6)
Spectrum price						
Average effect	-0.000413***		-0.000580***		-0.259	
Impact in first year		0.000156		-0.00007		-0.330
Impact in second year		-0.000980***		-0.00142***		-0.545
Impact after two years		-0.00240***		-0.00197**		-0.0888
Spectrum policy						
3G spectrum holdings	0.000506	0.000502	-0.000557	-0.000565	0.00120	0.00117

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

Full regression outputs (including other controls) are presented in Annex 1.

FIGURE 16B

INSTRUMENTAL VARIABLE REGRESSION RESULTS USING LOG OF $PPP/MHZ/POP/LICENCE YEAR

3G upload speeds (Mbps)

	All countries	Developing	Developed
Spectrum price			
Average effect	-0.0249	-0.353**	-0.0347
Spectrum policy			
3G Spectrum holdings	0.00115***	-0.00194**	0.00183***

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

Coefficients represent results of second-stage regressions. Full regression outputs are presented in Annex 1.

4.2.4 3G latencies

Figures 17a and 17b present results for 3G latencies. The results for the CPR regressions show that higher spectrum prices had significant negative impacts in developing countries, with impacts again materialising in the medium to long term. In this case, a 1pp increase in the cost of spectrum using CPR drove an increase in latencies of 0.65 milliseconds after two years. The findings are robust to all checks (see Annex 1). The results of the IV regressions for the PPP metric also suggest a negative impact but it is not statistically significant. In terms of developed countries, the CPR regressions suggest no impact while the IV analysis indicates that higher spectrum prices were associated with lower (i.e. improved) latencies. However, we treat the latter with caution as testing for over-identification suggests the instruments may not be valid when considering 3G latencies (see Annex 1).

We therefore interpret the results as providing firm, though not definitive, evidence that higher spectrum prices had a negative impact on 3G latencies in developing countries. In developed countries, the results are inconclusive.

FIGURE 17A

OLS REGRESSION RESULTS USING CPR

3G latencies (ms)

	All countries		Developing		Developed	
	(1)	(2)	(3)	(4)	(5)	(6)
Spectrum price						
Average effect	0.0809***		0.0807***		2.886	
Impact in first year		-0.0478**		-0.0620**		-10.18
Impact in second year		0.109**		0.121**		25.01
Impact after two years		0.584***		0.649***		10.52
Spectrum policy						
3G spectrum holdings	0.00772	0.00840	0.0252	0.0272	-0.0308	-0.0323

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

Full regression outputs (including other controls) are presented in Annex 1.

FIGURE 17B

INSTRUMENTAL VARIABLE REGRESSION RESULTS USING LOG OF $PPP/MHZ/POP/LICENCE YEAR

3G latencies (ms)

	All countries	Developing	Developed
Spectrum price			
Average effect	7.919	11.02	-20.41**
Spectrum policy			
3G Spectrum holdings	-0.105**	0.0267	0.0774

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

Coefficients represent results of second-stage regressions. Full regression outputs are presented in Annex 1.

4.3 All networks

In the following section, we report the results on average network quality across all technologies. One issue in using average quality is that it combines two underlying metrics, namely network quality and take-up of newer technologies. For example, operators may have the same levels of network quality on their 3G and 4G networks (e.g. the same average download speeds) but if one operator has a greater proportion of its consumers using 4G, then they will have higher overall download speeds.

Nevertheless, the metric is useful to provide a broader picture about whether spectrum prices can result in overall network quality changes, particularly as a significant proportion of mobile users in developing countries still used 2G in the early period of our analysis.

4.3.1 All download speeds

Figures 18a and 18b present results for download speeds across all networks. The results for the CPR regressions show that higher spectrum prices had significant negative impacts in developing countries, with impacts materialising after one year. The findings are robust to all alternative specifications (see Annex 1). We also find a negative impact in the IV regression for the PPP metric, with a 1% increase in spectrum price driving a 0.09 Mbps reduction in download speeds.

For developed countries, the IV regressions show a negative impact, though we treat the results with caution as the instruments may not be valid in this case.[31] The main CPR regression does not suggest any impact, though some of the alternative specifications (see Annex 1) show a negative impact – for example, when standard errors are clustered at the operator level and when we apply a logarithmic transformation of download speeds.

We therefore interpret the results to suggest that higher spectrum prices have a clear negative impact in developing countries, while for developed countries there is some evidence of a negative impact, though it is limited.

In terms of other control variables and policy factors, the amount of 4G spectrum holdings has a positive impact on download speeds in both developed and developing countries, with an additional 1 MHz of spectrum driving an increase in average download speeds of 0.06-0.12 Mbps. Therefore, an additional allocation of 20 MHz to an operator would, on average, increase download speeds by 1-2.5 Mbps.

FIGURE 18A

OLS REGRESSION RESULTS USING CPR

All download speeds (Mbps)

	All countries		Developing		Developed	
	(1)	(2)	(3)	(4)	(5)	(6)
Spectrum price						
Average effect	-0.0137***		-0.0111**		-17.16	
Impact in first year		0.0131		0.0100		-9.905
Impact in second year		-0.0288***		-0.0227**		-19.96
Impact after two years		-0.115		-0.0898		-14.52
Spectrum policy						
4G spectrum holdings	0.0680***	0.0679***	0.0902**	0.0901**	0.0601***	0.0614***
3G spectrum holdings	0.00443	0.00429	-0.0174*	-0.0176*	0.00736	0.00765

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

Full regression outputs (including other controls) are presented in Annex 1.

31. See p-value for over-identification in Annex 1.

FIGURE 18B

INSTRUMENTAL VARIABLE REGRESSION RESULTS USING LOG OF $PPP/MHZ/POP/LICENCE YEAR

All download speeds (Mbps)

	All countries	Developing	Developed
Spectrum price			
Average effect	-6.699***	-9.151***	-4.797***
Spectrum policy			
4G Spectrum holdings	0.0797***	0.118***	0.0609***
3G Spectrum holdings	0.0324***	-0.0585***	0.0404***

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

Coefficients represent results of second-stage regressions. Full regression outputs are presented in Annex 1.

4.3.2 All upload speeds

Figures 19a and 19b present results for upload speeds across all networks. The results for the CPR regressions do not suggest a significant impact in either developed or developing countries, though some of the alternative specifications presented in Annex 1 do have negative and statistically significant impacts for both developing and developed countries – for example, the model where we log transform upload speeds. The IV regressions for the PPP metric suggest that spectrum prices had a negative impact in both developing and developed countries, though the latter must be interpreted with some caution as the instruments may not be valid when applied to upload speeds.[32]

We therefore interpret the findings that there is some evidence to suggest higher spectrum prices had a negative impact on upload speeds in developing countries, though this is not definitive, while evidence of impact is more limited in developed countries.

In terms of other control variables and policy factors, the amount of 4G spectrum holdings has a positive impact, particularly in developed countries.

FIGURE 19A

OLS REGRESSION RESULTS USING CPR

All upload speeds (Mbps)

	All countries		Developing		Developed	
	(1)	(2)	(3)	(4)	(5)	(6)
Spectrum price						
Average effect	-0.00419*		-0.00340		-3.252	
Impact in first year		0.00743		0.00653		-3.688
Impact in second year		-0.00641*		-0.00430		-3.440
Impact after two years		-0.0518		-0.0443		0.586
Spectrum policy						
4G spectrum holdings	0.0242***	0.0242***	0.0331	0.0331	0.0188***	0.0191***
3G spectrum holdings	-0.000412	-0.000470	-0.0117*	-0.0118*	0.00351	0.00306

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

Full regression outputs (including other controls) are presented in Annex 1.

32. See Annex 1 for over-identification diagnostics.

FIGURE 19B

INSTRUMENTAL VARIABLE REGRESSION RESULTS USING LOG OF $PPP/MHZ/POP/LICENCE YEAR

All upload speeds (Mbps)

	All countries	Developing	Developed
Spectrum price			
Average effect	-3.698***	-3.958**	-3.172***
Spectrum policy			
4G Spectrum holdings	0.0309***	0.0470***	0.0187***
3G Spectrum holdings	0.0170***	-0.0295***	0.0283***

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

Coefficients represent results of second-stage regressions. Full regression outputs are presented in Annex 1.

4.3.3 All latencies

Figures 20a and 20b present results for latencies across all networks. The results for the CPR regressions show that higher spectrum prices had significant negative impacts in developing countries, with impacts materialising after one year. The findings are robust to alternative specifications (see Annex 1), though they are not significant when we apply the IV regression to the PPP metric. There is no evidence to suggest any impact in developed countries.

We therefore interpret the findings that there is some (though not definitive) evidence that higher spectrum prices increased latencies in developing countries, with limited impacts in developed countries.

In terms of other control variables and policy factors, the amount of 4G spectrum holdings has a positive impact on latencies in developed countries, with an additional 1 MHz of spectrum associated with a reduction in latencies of 0.18ms.

FIGURE 20A

OLS REGRESSION RESULTS USING CPR

All latencies (ms)

	All countries		Developing		Developed	
	(1)	(2)	(3)	(4)	(5)	(6)
Spectrum price						
Average effect	0.126***		0.116***		17.09	
Impact in first year		-0.0990		-0.125*		51.80
Impact in second year		0.203**		0.219**		6.748
Impact after two years		1.008***		1.081***		-32.04
Spectrum policy						
4G spectrum holdings	-0.194***	-0.193***	-0.297	-0.296	-0.176***	-0.177***
3G spectrum holdings	-0.104	-0.103	-0.367	-0.363	-0.0260	-0.0184

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

Full regression outputs (including other controls) are presented in Annex 1.

FIGURE 20B

INSTRUMENTAL VARIABLE REGRESSION RESULTS USING LOG OF $PPP/MHZ/POP/LICENCE YEAR

All latencies (ms)

	All countries	Developing	Developed
Spectrum price			
Average effect	27.36***	26.10	-0.0789
Spectrum policy			
4G Spectrum holdings	-0.260***	-0.435***	-0.175***
3G Spectrum holdings	-0.166***	-0.107	0.00994

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

Coefficients represent results of second-stage regressions. Full regression outputs are presented in Annex 1.

4.4 Consumer prices

In this sub-section, we present the results of our analysis at the operator level using ARPU as the dependent variable. We then present the analysis at the country level using the ITU price baskets.

4.4.1 ARPU

Figure 21 presents the results of the IV regression using the PPP metric. We do not present the CPR metric when looking at the impact on ARPU because operator revenues are present on both sides of the equation.

The IV results suggest that higher spectrum prices drove higher ARPU levels in developing countries, with a 1% increase in spectrum price linked to a 0.18% increase in ARPU. The results for developed countries suggest that higher spectrum costs were linked to a reduction in ARPU, though we treat this result with caution as the over-identification p-value suggests that the instruments for developed countries may not be valid when considering ARPU (see Annex 1).

Figure 22 present results of a DPD regression, using a system GMM estimator (further details and results are presented in Annex 1). This approach includes external instruments (the same instruments that are used in the IV regressions) as well as internal instruments. The results suggest there is some evidence that excessive spectrum prices (above the inner and outer fence) in developing countries drove higher ARPU. The results for developed countries suggest that higher spectrum prices drove higher ARPU, which is contrary to the IV results presented in Figure 21.

FIGURE 21

INSTRUMENTAL VARIABLE REGRESSION RESULTS USING LOG OF $PPP/MHZ/POP/LICENCE YEAR

Log of ARPU ($PPP)

	All countries	Developing	Developed
Spectrum price			
Average effect	-0.100***	0.180***	-0.0611***

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

Coefficients represent results of second-stage regressions. Full regression outputs are presented in Annex 1.

FIGURE 22

ARELLANO-BOND REGRESSION RESULTS USING LOG OF $PPP/MHZ/POP/LICENCE YEAR

	Log of ARPU ($PPP)		
	All countries	Developing	Developed
	(1)	(2)	(3)
Spectrum price			
Average effect	0.00480	0.00009	0.00459**
Spectrum price outliers			
75th percentile	0.00302*	0.00367	0.00271
Inner fence	0.00621**	0.0133**	0.00314
Outer fence	0.00895	0.0187**	0.00330

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

Full regression outputs are presented in Annex 1.

4.4.2 ITU basket prices

Figure 23 presents regression results using the CPR metric at the country level for ITU basket prices. As basket prices are more reflective of prices paid by consumers and are not calculating using revenue, it is reasonable to consider the CPR metric in this case. The results show that higher spectrum costs as a proportion of revenue drive higher prices for both voice and mobile broadband, particularly in developing countries (where such baskets are more likely to be representative, as discussed in Section 3.5). The results suggest that a 1pp increase in the cost of spectrum as a percentage of revenue increases the monthly price of the voice basket by 0.2% and the 500 MB mobile broadband basket by 0.5%.[33] These results hold if we calculate CPR using future revenues instead of current revenues (results presented in Annex 1). While we present the results for developed countries, which generally show insignificant results, we do not give much weight to the analysis given the limited relevance of the baskets for most of the 2010-2017 period.

Figure 24 presents the results of the instrumental variable analysis using the PPP metric. These suggest that the impact of higher spectrum prices in developing countries was not significant[34], though the diagnostics provided in Annex 1 also suggest that the instruments used work less well when applied to country-level data as we cannot reject the null hypothesis that they are weakly identified for developing countries. We therefore treat the results of the IV regressions with caution.

FIGURE 23

OLS REGRESSION RESULTS USING CPR

	Log of basket price ($PPP)					
	All countries		Developing		Developed	
	Voice Basket	MBB Basket	Voice Basket	MBB Basket	Voice Basket	MBB Basket
Spectrum price						
Average effect	0.00146***	0.00505***	0.00201**	0.00488***	-1.275	2.068

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

Full regression outputs (including other controls) are presented in Annex 1.

33. As we apply a logarithmic transformation on the basket price but not CPR, the coefficient can be interpreted as follows: a 1pp increase in CPR is linked to a (β*100)% change in the dependent variable – in this case price.

34. This is also in line with the DPD analysis, presented in Annex 1.

FIGURE 24

INSTRUMENTAL VARIABLE REGRESSION RESULTS USING LOG OF $PPP/MHZ/POP/LICENCE YEAR

Log of basket price ($PPP)

	All countries		Developing		Developed	
	Voice Basket	MBB Basket	Voice Basket	MBB Basket	Voice Basket	MBB Basket
Spectrum price						
Average effect	-0.127	-0.0599	1.468	-1.834	-0.128	-0.155

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

Coefficients represent results of second-stage regressions. Full regression outputs are presented in Annex 1.

Taking all the results on ARPU and price baskets in the round, Figure 25 presents a summary of the findings. We conclude there is some evidence that higher spectrum costs may have driven higher consumer prices in developing countries but it is not definitive. The evidence for developed countries is inconclusive given the inconsistency in results for ARPU and the fact that the ITU price baskets considered in this study are unlikely to be representative of consumption patterns in these markets during most of the period.

Going forward, better and more comprehensive data on mobile prices is required in order to reach more definitive conclusions on the effects of spectrum prices on consumer tariffs.

FIGURE 25

SUMMARY OF FINDINGS ON CONSUMER PRICES

	Developing countries	Developed countries
ARPU-IV regression	Evidence that high spectrum prices drive higher ARPU	Higher spectrum prices linked to lower ARPUs, though results treated with caution given regression diagnostics
ARPU-Arellano Bond regression	Some evidence that very high spectrum prices (above inner and outer fence) are linked to higher ARPU	Some evidence that higher spectrum prices are linked to higher ARPU
ITU baskets – CPR regression	Evidence that higher CPR drives higher consumer prices	No evidence of impact, though basket unlikely to be relevant
ITU baskets – IV and Arellano Bond regression	No statistically significant results, though results treated with caution given regression diagnostics	No evidence of impact, though basket unlikely to be relevant

Summary of results

Figure 26 provides an overall summary of the results regarding the impact of high spectrum prices for each of the consumer outcomes considered in this study.

FIGURE 26

SUMMARY OF FINDINGS ON CONSUMER OUTCOMES

	Developing countries	Developed countries
4G coverage	 Strong evidence of a negative impact	 Strong evidence of a negative impact
4G download speeds	 Evidence suggests impact was negligible or otherwise inconclusive	 Strong evidence of a negative impact
4G upload speeds	 Some evidence of a negative impact but not definitive	 Some evidence of a negative impact but not definitive
4G latencies	 No evidence of any impact	 No evidence of any impact
3G coverage	 Some evidence of a negative impact but not definitive	Not applicable as 3G coverage was already rolled out in most countries by 2010
3G download speeds	 Strong evidence of a negative impact	 Some evidence of a negative impact but not definitive
3G upload speeds	 Strong evidence of a negative impact	 No evidence of any impact
3G latencies	 Some evidence of a negative impact but not definitive	 Evidence suggests impact was negligible or otherwise inconclusive
All download speeds	 Strong evidence of a negative impact	 Some evidence of a negative impact but not definitive
All upload speeds	 Some evidence of a negative impact but not definitive	 Some evidence of a negative impact but not definitive
All latencies	 Some evidence of a negative impact but not definitive	 Limited evidence of any impact
Consumer prices	 Some evidence of a negative impact but not definitive	Inconclusive as better data is required

5. Conclusions

The results of this study are, to our knowledge, the first robust evidence that shows how more expensive spectrum can harm – and indeed has harmed – consumers in mobile markets. In particular, the study shows the following:

- Higher spectrum prices played a significant role in slowing the rollout of new generation mobile networks. This was the case for 4G networks in developed countries and both 3G and 4G networks in developing countries.
- More expensive spectrum also had a significant effect in reducing the network quality experienced by consumers in both developed and developing countries.
- Higher spectrum prices are associated with higher consumer prices in developing countries, though further research is needed to confirm whether the effect is robust.
- Other policy factors play a significant role in slowing network rollout (i.e. reduced coverage) and reducing the quality of 3G and 4G networks. In particular, early release of spectrum and a sufficient amount of licenced spectrum are both found to be important drivers of consumer welfare.

These findings have important ramifications for regulators, especially when so many are trying to prioritise improved coverage and increased investment in 4G and 5G. In particular, the results suggest that:

- Efforts to maximise spectrum revenues may not be consistent with government objectives to leverage mobile technology to reduce poverty and achieve economic prosperity.
- Auctions can deliver inefficient outcomes if they are poorly designed and result in higher prices or spectrum being unsold.
- Early release of spectrum bands is important to ensure that new mobile services can be launched and existing services can be enhanced.

These are discussed in more detail in an accompanying policy report.[35]

35. The impact of spectrum prices on consumers, GSMA, 2019

Annex 1: Additional econometric results

In this Annex, we present the full set of outputs from our econometric models. For each consumer outcome, the results presented are as follows:

1. the results of the CPR regressions (using OLS regression)

2. the results of four alternative CPR specifications for robustness checks:
   - cluster standard errors at the operator level
   - MNO fixed effects model
   - non-linear functional forms[36]
   - CPR calculated using future revenues rather than current revenues

3. the OLS results using the $PPP metric

4. the results of the IV regressions using the PPP metric.

For consumer pricing, we also present additional outputs of the DPD models.

With regards to the instrumental variable regressions, we checked a number of diagnostics[37] to determine whether the instruments and results are valid. These are presented in Figure A1.1.

FIGURE A1.1

INSTRUMENTAL VARIABLE REGRESSION DIAGNOSTICS

Diagnostic/test statistic	Interpretation
Under-identification p-value P-value of the Kleibergen-Paap rk LM statistic.	Null hypothesis is that the model is underidentified. Rejecting the null at the 5% level (i.e. p<0.05) indicates that instruments are not underidentified and are therefore correlated with the spectrum price.
Weak identification p-value. P-value of the Sanderson-Windmeijer statistic	Null hypothesis is that instruments are weakly correlated with spectrum price. Rejecting the null at the 5% level (i.e. p<0.05) indicates that instruments are not weakly correlated with spectrum price.
Weak identification F-Statistic. Kleibergen-Paap Wald rk F-statistic for weak identification	An additional check for weak identification compares this F-Statistic with the critical Stock-Yogo values. For developed country regressions (one endogenous variable and three instruments), a 5% maximal IV relative bias corresponds to a critical value greater than 13.91 while a 10% maximum IV relative bias corresponds to a critical value greater than 9.08. For all country regressions (one endogenous variable and four instruments), a 5% maximal IV relative bias corresponds to a critical value greater than 16.85 while a 10% maximum IV relative bias corresponds to a critical value greater than 10.27. For developing country regressions (one endogenous variable and one instrument), a 10% maximal IV size corresponds to a critical value greater than 16.38 while a 15% maximal IV size corresponds to a critical value greater than 8.96.
Over-identification p-value P-value of the Hansen's J statistic (where more than one instrument is used)	Null hypothesis is that instruments are uncorrelated with the error term. Rejecting the null at the 5% level (i.e. p<0.05) indicates that instruments are not valid. Can only be estimated if there are more instruments than endogenous regressors.
Endogeneity p-value. p-value of the endogeneity test (C statistic)	Null hypothesis is that the specified endogenous regressors can actually be treated as exogenous. Rejecting the null at the 5% level (i.e. p<0.05) indicates that instruments are endogenous, though this interpretation is conditional on the instruments being valid.

36. We apply logarithmic transformations to the dependent variables (with the exception of consumer price outcomes as these are log-transformed already). In the case of 3G and 4G coverage, we apply a logit transformation as this is more appropriate for indicators that are bounded between 0 and 1 (as the dependent variable is a proportion of total population).
37. All diagnostics and test statistics are those reported following the ivreg2 command in Stata.

A1.1 4G networks

A1.1.1 4G coverage

Figure A1.2

OLS REGRESSION RESULTS USING CPR

	4G coverage (percentage of population)					
	All countries		Developing		Developed	
	(1)	(2)	(3)	(4)	(5)	(6)
Spectrum price						
Average effect	-4.746***		-4.793***		-86.34*	
	(1.478)		(1.664)		(47.52)	
Impact in first year		-3.423***		-3.595***		-72.53**
		(0.971)		(1.257)		(35.03)
Impact in second year		-3.750***		-3.958**		-65.78
		(1.218)		(1.494)		(53.50)
Impact after two years		-6.228**		-6.075**		-62.85
		(2.522)		(2.599)		(58.96)
Controls						
HHI	-27.41**	-26.95**	-49.27	-48.57	-18.46	-19.06
	(12.44)	(12.45)	(30.46)	(30.82)	(21.43)	(21.68)
Market share	0.313***	0.311***	0.358***	0.356***	0.232**	0.249**
	(0.0901)	(0.0903)	(0.109)	(0.111)	(0.102)	(0.102)
GDP per capita	30.64	30.30	49.71	48.64	25.08	30.04
	(31.37)	(31.53)	(50.15)	(51.31)	(19.56)	(19.94)
Urban population %	-3.947	-3.672	-1.615	-1.130	-1.482	-1.527
	(4.306)	(4.292)	(5.436)	(5.380)	(8.208)	(8.127)
Population density	74.26	76.08	210.2	208.4	118.1	123.4
	(123.2)	(124.0)	(214.0)	(216.9)	(101.1)	(93.19)
3G coverage	0.0211	0.0202	-0.0592	-0.0617	0.322**	0.327**
	(0.0807)	(0.0820)	(0.0858)	(0.0875)	(0.120)	(0.121)
4G spectrum holdings	0.106***	0.105***	0.0876	0.0818	0.0982***	0.0999***
	(0.0226)	(0.0230)	(0.0674)	(0.0705)	(0.0185)	(0.0191)
4G spectrum: 1-2 years	9.539***	9.654***	9.603***	9.717***	7.897**	7.835**
	(2.145)	(2.167)	(2.024)	(2.115)	(3.085)	(3.159)
4G spectrum: 2+ years	15.56***	15.97***	11.63***	12.30***	14.93***	14.75***
	(2.859)	(2.949)	(3.441)	(3.921)	(3.644)	(3.693)
Smartphone adoption	36.53**	36.91**	29.61	29.22	40.80*	41.33*
	(16.67)	(16.77)	(18.85)	(19.39)	(22.06)	(21.94)
Coverage obligation	4.114	3.922	3.616	3.288	5.179	4.594
	(4.443)	(4.408)	(7.529)	(7.500)	(5.675)	(5.579)
Constant	-131.1	-159.6	-833.9	-852.5	-559.7	-628.9
	(777.6)	(777.3)	(1,228)	(1,252)	(814.7)	(784.3)
Country FE	yes	yes	yes	yes	yes	yes
Time FE	yes	yes	yes	yes	yes	yes
Observations	2,655	2,655	900	900	1,754	1,754
R-squared	0.788	0.789	0.752	0.753	0.807	0.805

Cluster-robust standard errors in parentheses

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

Figure A1.3

ROBUSTNESS CHECKS USING CPR

	4G coverage (percentage of population)				
	(1)	(2)	(3)	(4)	(5)
	All countries				
Average effect	-4.746***	-4.746***	-2.266***	-0.528***	-2.922***
Impact in first year	-3.423***	-3.423**	-2.015**	-0.462***	-2.041***
Impact in second year	-3.750***	-3.750***	-2.309**	-0.293**	-2.178***
Impact after two years	-6.228**	-6.228***	-4.610**	-0.725***	-5.729***
4G spectrum holdings	0.106***	0.106***	0.116***	0.0116***	0.105***
4G spectrum: 1-2 years	9.539***	9.539***	9.551***	1.242***	9.241***
4G spectrum: 2+ years	15.56***	15.56***	18.07***	1.338***	14.93***
	Developing countries				
Average effect	-4.793***	-4.793***	-3.684***	-0.581***	-2.740***
Impact in first year	-3.595***	-3.595**	-3.199***	-0.544***	-1.891***
Impact in second year	-3.958**	-3.958***	-3.694***	-0.350**	-2.209***
Impact after two years	-6.075**	-6.075**	-5.515***	-0.756***	-5.215***
4G spectrum holdings	0.0876	0.0876	0.161***	0.0105	0.0973
4G spectrum: 1-2 years	9.603***	9.603***	10.21***	1.267***	9.078***
4G spectrum: 2+ years	11.63***	11.63***	16.37***	0.762	10.29***
	Developed countries				
Average effect	-86.34*	-86.34**	41.45*	-9.530*	-84.53
Impact in first year	-72.53**	-72.53**	10.06	-9.767***	-67.39*
Impact in second year	-65.78	-65.78	43.45*	-9.018	-63.08
Impact after two years	-62.85	-62.85	45.11	-4.577	-68.11
4G spectrum holdings	0.0982***	0.0982***	0.0814***	0.0103***	0.103***
4G spectrum: 1-2 years	7.897**	7.897***	8.371***	1.167***	7.683**
4G spectrum: 2+ years	14.93***	14.93***	15.88***	1.569***	14.68***
Standard error clusters	Country	Operator	Operator	Country	Country
Country or operator FE	Country	Country	Operator	Country	Country
Time FE	Yes	Yes	Yes	Yes	Yes
Logit transformation of 4G coverage	No	No	No	Yes	No
Current or Future Revenues	Current	Current	Current	Current	Future

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

Figure A1.4

OLS REGRESSION RESULTS USING LOG OF $PPP/MHZ/POP/LICENCE YEAR

	4G coverage (percentage of population)					
	All countries		Developing		Developed	
	(1)	(2)	(3)	(4)	(5)	(6)
Spectrum price						
Average effect	0.762		6.542**		-0.466	
	(1.784)		(2.715)		(2.217)	
Impact in first year		-0.0897		0.263		-0.485*
		(0.190)		(0.217)		(0.270)
Impact in second year		0.164		0.849***		-0.452
		(0.271)		(0.260)		(0.379)
Impact after two years		0.208		0.851**		-0.318
		(0.279)		(0.335)		(0.373)
Controls						
HHI	-20.07	-18.33	-58.54*	-58.29*	-8.223	-2.728
	(12.77)	(11.71)	(31.26)	(28.99)	(16.33)	(15.09)
Market share	0.371***	0.378***	0.386***	0.456***	0.329**	0.325***
	(0.108)	(0.105)	(0.130)	(0.143)	(0.125)	(0.115)
GDP per capita	36.87	35.34	32.21	41.03	45.12**	48.75**
	(33.74)	(32.10)	(51.96)	(47.61)	(22.07)	(19.43)
Urban population %	-3.857	-3.563	-4.360	-3.561	0.268	0.672
	(4.394)	(4.352)	(6.199)	(5.617)	(7.747)	(7.540)
Population density	48.63	45.34	137.9	166.5	123.4	136.9
	(130.1)	(125.5)	(225.7)	(207.8)	(94.39)	(99.74)
3G coverage	0.0812	0.0869	0.0145	0.0269	0.180***	0.183***
	(0.0614)	(0.0521)	(0.0996)	(0.0782)	(0.0645)	(0.0532)
4G spectrum holdings	0.0997***	0.104***	0.0719	0.0605	0.105***	0.114***
	(0.0231)	(0.0261)	(0.0544)	(0.0549)	(0.0193)	(0.0220)
4G spectrum: 1-2 years	8.496***	6.926***	9.299***	5.590***	7.461**	7.309**
	(1.980)	(1.990)	(2.003)	(1.838)	(2.766)	(2.917)
4G spectrum: 2+ years	13.21***	11.72***	10.32***	8.108*	12.59***	12.05***
	(2.588)	(2.635)	(2.910)	(3.936)	(3.488)	(3.605)
Smartphone adoption	33.27**	34.15**	18.53	32.40	40.27*	39.55*
	(16.58)	(16.42)	(22.17)	(21.50)	(22.41)	(21.69)
Coverage obligation	7.252	8.024	15.48*	11.73	1.944	2.973
	(6.313)	(6.086)	(8.502)	(10.34)	(5.464)	(4.877)
Constant	-153.3	-159.5	-93.12	-359.8	-1,010	-1,198
	(852.4)	(825.9)	(1,258)	(1,137)	(745.3)	(749.0)
Country FE	yes	yes	yes	yes	yes	yes
Time FE	yes	yes	yes	yes	yes	yes
Observations	2,806	2,806	926	926	1,879	1,879
R-squared	0.779	0.780	0.751	0.745	0.798	0.800

Cluster-robust standard errors in parentheses

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

Figure A1.5

INSTRUMENTAL VARIABLE REGRESSION RESULTS USING LOG OF $PPP/MHZ/POP/LICENCE YEAR

4G coverage (percentage of population)

	All countries		Developing		Developed	
	(1)	(2)	(3)	(4)	(5)	(6)
Instruments						
Short-term debt	0.000478		0.0292***			
	(0.00937)		(0.0101)			
Non-auction assignment	-0.373***				-0.596***	
	(0.102)				(0.125)	
Spectrum price in region	0.808***				0.489**	
	(0.246)				(0.235)	
Reserve price in region	0.113				0.129	
	(0.116)				(0.0933)	
Spectrum price						
Average effect		-5.723*		-53.46**		-16.40***
		(3.339)		(23.47)		(3.378)
Controls						
HHI	1.610***	3.585	0.439	-17.16	2.507***	33.46***
	(0.283)	(7.581)	(0.410)	(28.75)	(0.361)	(12.29)
Market Share	0.00802***	0.356***	0.0120***	1.080***	0.00831***	0.425***
	(0.00189)	(0.0440)	(0.00214)	(0.304)	(0.00217)	(0.0599)
GDP per capita	-2.843***	41.79***	0.740	78.62	-4.550***	-27.58
	(0.532)	(14.27)	(1.054)	(71.77)	(0.508)	(20.38)
Urban population %	0.258***	1.245	0.216***	14.01*	0.648***	10.82***
	(0.0767)	(1.784)	(0.0718)	(8.128)	(0.111)	(3.623)
Population density	-0.654	64.55*	2.273	169.2	9.536***	322.9***
	(1.774)	(38.65)	(2.503)	(159.4)	(2.397)	(65.77)
3G coverage	0.0157***	0.251***	0.00602***	0.402**	0.0185***	0.459***
	(0.00205)	(0.0651)	(0.00168)	(0.175)	(0.00257)	(0.0887)
4G spectrum holdings	0.00396***	0.135***	0.000172	0.117	0.00289***	0.159***
	(0.000540)	(0.0170)	(0.00118)	(0.0746)	(0.000589)	(0.0183)
4G spectrum: 1-2 years	-0.232***	8.793***	-0.000433	8.784**	-0.294***	5.902***
	(0.0696)	(1.406)	(0.0677)	(4.110)	(0.0904)	(2.197)
4G spectrum: 2+ years	-0.0835	14.60***	0.0710	12.90***	-0.0964	14.37***
	(0.0814)	(1.414)	(0.0799)	(4.857)	(0.104)	(2.265)
Smartphone adoption	-0.629*	23.78***	0.331	51.32*	-0.692**	36.86***
	(0.324)	(6.033)	(0.443)	(28.06)	(0.349)	(9.412)
Coverage obligation	0.622***	3.383	-0.663***	-23.95	1.794***	32.54***
	(0.137)	(3.010)	(0.116)	(17.22)	(0.159)	(7.026)
Constant	0.582	-749.8***	-27.57*	-1,734	-56.76***	-2,255***
	(9.287)	(190.7)	(15.27)	(1,117)	(16.52)	(440.8)
Country FE	yes	yes	yes	yes	yes	yes
Time FE	yes	yes	yes	yes	yes	yes
Observations	2,446		878		1,781	
Under identification p-value[1]	0.000		0.004		0.000	
Weak identification p-value[2]	0.000		0.004		0.000	
Weak identification F-Statistic[3]	7.634		8.367		13.460	
Overidentification p-value[4]	0.000		N/A		0.510	
Endogeneity p-value[5]	0.030		0.000		0.000	

Cluster-robust standard errors in parentheses

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

1. Reports the p-value of the Kleibergen-Paap rk LM statistic. Null hypothesis is that the model is underidentified.
2. Reports the p-value of the Sanderson-Windmeijer statistic. Null hypothesis is that the model is weakly identified.
3. Reports the Kleibergen-Paap Wald rk F-statistic for weak identification.
4. Reports the p-value of the Hansen's J statistic where more than one instrument is used. Joint null hypothesis is that the instruments are valid and not correlated with the error term.
5. Reports the p-value of the endogeneity test (C statistic). Null hypothesis is that the endogenous regressors are in fact exogenous.

A1.1.2 4G download speeds

Figure A1.6

OLS REGRESSION RESULTS USING CPR

4G download speeds (Mbps)

	All countries		Developing		Developed	
	(1)	(2)	(3)	(4)	(5)	(6)
Spectrum price						
Average effect	-0.0218		-0.212		-14.69	
	(0.452)		(0.597)		(14.81)	
Impact in first year		0.167		-0.164		-0.0466
		(0.307)		(0.450)		(11.50)
Impact in second year		-0.434		-0.418		-24.71
		(0.387)		(0.506)		(16.85)
Impact after two years		0.182		-0.0184		-23.80*
		(0.548)		(0.668)		(12.42)
Controls						
HHI	5.278	5.295	10.13	10.14	10.50	10.95
	(7.825)	(7.825)	(8.713)	(8.678)	(10.33)	(10.27)
Market share	0.0317	0.0324	-0.0155	-0.0140	0.0826	0.0756
	(0.0548)	(0.0547)	(0.0621)	(0.0620)	(0.0933)	(0.0933)
GDP per capita	-16.08	-16.06	18.29	18.35	-29.01**	-28.30**
	(12.24)	(12.24)	(16.62)	(16.69)	(10.67)	(10.43)
Urban population %	-3.360**	-3.339**	-4.815***	-4.799***	1.691	1.810
	(1.553)	(1.549)	(1.520)	(1.519)	(3.272)	(3.236)
Population density	-37.05	-37.16	-113.3**	-113.4**	70.38	76.06
	(43.63)	(43.63)	(50.54)	(50.61)	(64.40)	(64.54)
4G spectrum holdings	0.0238	0.0239	0.00192	0.00201	0.0311	0.0330
	(0.0163)	(0.0163)	(0.0398)	(0.0398)	(0.0206)	(0.0213)
QoS obligation	1.419	1.404	-1.838	-1.864*	2.625	2.584
	(2.701)	(2.701)	(1.089)	(1.087)	(4.086)	(4.075)
Constant	564.3**	562.8**	559.9*	558.4	-222.9	-270.5
	(257.9)	(257.5)	(328.1)	(328.7)	(454.8)	(455.0)
Country FE	yes	yes	yes	yes	yes	yes
Time FE	yes	yes	yes	yes	yes	yes
Observations	2,912	2,912	1,032	1,032	1,880	1,880
R-squared	0.443	0.444	0.560	0.560	0.358	0.363

Cluster-robust standard errors in parentheses

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

Figure A1.7

ROBUSTNESS CHECKS USING CPR

	4G download speeds (Mbps)				
	(1)	(2)	(3)	(4)	(5)
	All countries				
Average effect	-0.0218	-0.0218	0.0254	-0.00543	-0.0708
Impact in first year	0.167	0.167	0.270	0.00747	-0.0150
Impact in second year	-0.434	-0.434	-0.0964	-0.0110	-0.231
Impact after two years	0.182	0.182	-0.428	-0.00687	0.176
4G spectrum holdings	0.0238	0.0238*	-0.0109	0.000938*	0.0234
	Developing countries				
Average effect	-0.212	-0.212	1.148***	-0.0146	-0.0751
Impact in first year	-0.164	-0.164	1.149**	-0.00461	-0.118
Impact in second year	-0.418	-0.418	1.104**	-0.0156	-0.144
Impact after two years	-0.0184	-0.0184	0.857	-0.0162	0.183
4G spectrum holdings	0.00192	0.00192	-0.0769**	0.000648	0.00120
	Developed countries				
Average effect	-14.69	-14.69	-4.858	-0.452	-10.69
Impact in first year	-0.0466	-0.0466	4.300	-0.231	-3.518
Impact in second year	-24.71	-24.71*	-18.48	-0.644	-15.04
Impact after two years	-23.80*	-23.80**	-15.86	-0.592	-14.35*
4G spectrum holdings	0.0311	0.0311*	0.0137	0.000953	0.0303
Standard error clusters	Country	Operator	Operator	Country	Country
Country or operator FE	Country	Country	Operator	Country	Country
Time FE	Yes	Yes	Yes	Yes	Yes
Log transformation of 4G download speeds	No	No	No	Yes	No
Current or Future Revenues	Current	Current	Current	Current	Future

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

Figure A1.8

OLS REGRESSION RESULTS USING LOG OF $PPP/MHZ/POP/LICENCE YEAR

4G download speeds (Mbps)

	All countries		Developing		Developed	
	(1)	(2)	(3)	(4)	(5)	(6)
Spectrum price						
Average effect	0.352		-0.660		0.470	
	(0.473)		(1.187)		(0.534)	
Impact in first year		0.0849		-0.0339		0.0589
		(0.0868)		(0.150)		(0.0797)
Impact in second year		-0.0688		-0.0716		-0.0793
		(0.102)		(0.130)		(0.111)
Impact after two years		-0.106		0.0674		-0.186*
		(0.0844)		(0.133)		(0.102)
Controls						
HHI	3.560	4.205	12.91	11.18	6.327	6.199
	(8.429)	(8.211)	(8.020)	(8.916)	(10.67)	(10.24)
Market share	0.0241	0.0279	0.00163	-0.00746	0.0653	0.0729
	(0.0442)	(0.0434)	(0.0529)	(0.0520)	(0.0699)	(0.0700)
GDP per capita	-14.84	-15.46	18.63	16.87	-24.23**	-26.32**
	(11.73)	(12.35)	(16.62)	(17.00)	(9.579)	(9.716)
Urban population %	-3.191**	-3.040**	-4.761***	-4.639***	2.450	2.348
	(1.559)	(1.500)	(1.458)	(1.453)	(3.610)	(3.497)
Population density	-36.33	-31.79	-115.5**	-116.1**	78.93	83.72
	(43.23)	(42.57)	(50.36)	(50.12)	(64.95)	(64.39)
4G spectrum holdings	0.0224	0.0229	0.000462	0.00196	0.0316	0.0313
	(0.0157)	(0.0160)	(0.0387)	(0.0397)	(0.0203)	(0.0207)
QoS obligation	0.727	0.970	-1.684	-1.810	0.695	1.199
	(2.416)	(2.425)	(1.128)	(1.247)	(3.963)	(3.558)
Constant	552.5**	519.2**	535.7	563.9*	-340.4	-336.3
	(252.5)	(250.2)	(325.4)	(324.0)	(474.1)	(482.2)
Country FE	yes	yes	yes	yes	yes	yes
Time FE	yes	yes	yes	yes	yes	yes
Observations	3,014	3,014	1,052	1,052	1,962	1,962
R-squared	0.436	0.439	0.555	0.555	0.352	0.359

Cluster-robust standard errors in parentheses

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

Figure A1.9

INSTRUMENTAL VARIABLE REGRESSION RESULTS USING LOG OF $PPP/MHZ/POP/LICENCE YEAR

4G download speeds (Mbps)

	All countries		Developing		Developed	
	First stage	Second stage	First stage	Second stage	First stage	Second stage
Instruments						
Short-term debt	0.0365***		0.0454***			
	(0.00754)		(0.00831)			
Non-auction assignment	-0.379***				-0.391***	
	(0.0760)				(0.0746)	
Spectrum price in region	0.375*				0.0678	
	(0.194)				(0.254)	
Reserve price in region	0.110				0.372**	
	(0.101)				(0.184)	
Spectrum price						
Average effect		-5.977***		7.074*		-7.475***
		(1.787)		(3.821)		(2.597)
Controls						
HHI	0.795***	12.31***	0.863***	3.861	1.056***	18.23***
	(0.264)	(3.986)	(0.308)	(6.757)	(0.349)	(5.622)
Market Share	0.00758***	0.0918***	0.00982***	-0.0437	0.0120***	0.173***
	(0.00162)	(0.0252)	(0.00171)	(0.0476)	(0.00229)	(0.0445)
GDP per capita	-3.171***	-40.39***	0.250	18.13	-4.476***	-62.55***
	(0.489)	(10.23)	(1.094)	(12.78)	(0.487)	(16.41)
Urban population %	-0.00267	-2.647***	0.0350	-5.485***	-0.0885	1.903
	(0.0460)	(0.800)	(0.0488)	(1.270)	(0.102)	(1.594)
Population density	0.370	-1.940	-1.522	-87.16**	2.445	124.1***
	(1.434)	(29.50)	(2.119)	(43.24)	(2.311)	(44.27)
4G spectrum holdings	0.00230***	0.0398***	0.00146	-0.0199	0.000836*	0.0394***
	(0.000398)	(0.00878)	(0.000929)	(0.0172)	(0.000438)	(0.00898)
QoS obligation	1.273***	8.994***	0.145*	-3.057*	1.799***	15.34***
	(0.0964)	(2.665)	(0.0740)	(1.723)	(0.126)	(5.168)
Constant	12.84*	265.2*	-8.875	370.1*	30.77**	-161.9
	(6.770)	(155.4)	(13.91)	(195.9)	(15.41)	(332.3)
Country FE	yes	yes	yes	yes	yes	yes
Time FE	yes	yes	yes	yes	yes	yes
Observations	2,756		1,011		1,870	
Under identification p-value[1]	0.000		0.000		0.000	
Weak identification p-value[2]	0.000		0.000		0.000	
Weak identification F-Statistic[3]	17.680		29.85		12.400	
Overidentification p-value[4]	0.672		N/A		0.748	
Endogeneity p-value[5]	0.000		0.023		0.001	

Cluster-robust standard errors in parentheses

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

1. Reports the p-value of the Kleibergen-Paap rk LM statistic. Null hypothesis is that the model is underidentified.
2. Reports the p-value of the Sanderson-Windmeijer statistic. Null hypothesis is that the model is weakly identified.
3. Reports the Kleibergen-Paap Wald rk F-statistic for weak identification.
4. Reports the p-value of the Hansen's J statistic where more than one instrument is used. Joint null hypothesis is that the instruments are valid and not correlated with the error term.
5. Reports the p-value of the endogeneity test (C statistic). Null hypothesis is that the endogenous regressors are in fact exogenous.

A1.1.3 4G upload speeds

Figure A1.10

OLS REGRESSION RESULTS USING CPR

	4G upload speeds (Mbps)					
	All countries		Developing		Developed	
	(1)	(2)	(3)	(4)	(5)	(6)
Spectrum price						
Average effect	-0.438**		-0.536**		-0.544	
	(0.169)		(0.203)		(4.474)	
Impact in first year		-0.247		-0.368*		0.741
		(0.177)		(0.212)		(3.746)
Impact in second year		-0.172		-0.219		-1.505
		(0.149)		(0.189)		(4.783)
Impact after two years		-0.698***		-0.816***		-1.543
		(0.236)		(0.256)		(3.985)
Controls						
HHI	1.069	1.082	3.025	3.147	2.075	2.116
	(3.653)	(3.662)	(2.737)	(2.792)	(5.473)	(5.493)
Market share	-0.0184	-0.0189	-0.0363	-0.0372	0.0143	0.0136
	(0.0306)	(0.0306)	(0.0370)	(0.0370)	(0.0504)	(0.0499)
GDP per capita	-4.009	-4.067	3.241	3.059	-4.890	-4.869
	(3.226)	(3.218)	(3.834)	(3.969)	(4.219)	(4.110)
Urban population %	-0.310	-0.319	-0.912	-0.938	1.091	1.097
	(0.480)	(0.483)	(0.726)	(0.731)	(1.004)	(0.997)
Population density	-3.888	-3.831	-13.06	-13.12	17.30	17.74
	(13.63)	(13.62)	(15.04)	(15.06)	(19.92)	(19.94)
4G spectrum holdings	0.00480	0.00468	-0.00455	-0.00494	0.00565	0.00579
	(0.00761)	(0.00759)	(0.0245)	(0.0244)	(0.00821)	(0.00828)
QoS obligation	-0.191	-0.177	-2.203**	-2.173**	0.677	0.676
	(1.631)	(1.630)	(0.915)	(0.910)	(2.308)	(2.301)
Constant	86.07	87.01	72.44	75.10	-121.9	-125.0
	(72.89)	(73.09)	(83.91)	(85.85)	(143.2)	(140.8)
Country FE	yes	yes	yes	yes	yes	yes
Time FE	yes	yes	yes	yes	yes	yes
Observations	2,912	2,912	1,032	1,032	1,880	1,880
R-squared	0.344	0.345	0.444	0.448	0.282	0.282

Cluster-robust standard errors in parentheses

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

Figure A1.11

ROBUSTNESS CHECKS USING CPR

	4G upload speeds (Mbps)				
	(1)	(2)	(3)	(4)	(5)
	All countries				
Average effect	-0.438**	-0.438*	-0.117	-0.0414***	-0.169**
Impact in first year	-0.247	-0.247	-0.0573	-0.0196	-0.0964
Impact in second year	-0.172	-0.172	-0.0804	-0.0106	-0.0701
Impact after two years	-0.698***	-0.698**	-0.187	-0.0720***	-0.552***
4G spectrum holdings	0.00480	0.00480	-0.00468	0.000495	0.00431
	Developing countries				
Average effect	-0.536**	-0.536*	0.148	-0.0477***	-0.169*
Impact in first year	-0.368*	-0.368*	0.145	-0.0273	-0.120
Impact in second year	-0.219	-0.219	0.185	-0.0143	-0.0496
Impact after two years	-0.816***	-0.816***	0.0748	-0.0792***	-0.584***
4G spectrum holdings	-0.00455	-0.00455	-0.0216*	-0.000130	-0.00661
	Developed countries				
Average effect	-0.544	-0.544	3.106	-0.0246	-0.859
Impact in first year	0.741	0.741	2.734	-0.0103	-1.822
Impact in second year	-1.505	-1.505	0.620	-0.0145	-1.016
Impact after two years	-1.543	-1.543	-0.195	-0.0740	-0.252
4G spectrum holdings	0.00565	0.00565	0.00112	0.000438	0.00564
Standard error clusters	Country	Operator	Operator	Country	Country
Country or operator FE	Country	Country	Operator	Country	Country
Time FE	Yes	Yes	Yes	Yes	Yes
Log transformation of 4G upload speeds	No	No	No	Yes	No
Current or Future Revenues	Current	Current	Current	Current	Future

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

Figure A1.12

OLS REGRESSION RESULTS USING LOG OF $PPP/MHZ/POP/LICENCE YEAR

4G upload speeds (Mbps)

	All countries		Developing		Developed	
	(1)	(2)	(3)	(4)	(5)	(6)
Spectrum price						
Average effect	0.234		0.0227		0.198	
	(0.209)		(0.609)		(0.216)	
Impact in first year		0.0466		0.0114		0.0386
		(0.0409)		(0.0793)		(0.0319)
Impact in second year		0.0444		0.0193		0.0510
		(0.0482)		(0.0866)		(0.0414)
Impact after two years		-0.000128		0.0201		-0.0125
		(0.0435)		(0.0774)		(0.0479)
Controls						
HHI	-0.0593	-0.313	4.003	3.697	0.145	-0.470
	(3.977)	(3.894)	(2.482)	(3.004)	(5.696)	(5.601)
Market share	-0.0191	-0.0166	-0.0235	-0.0237	-0.00420	-0.000556
	(0.0255)	(0.0249)	(0.0328)	(0.0317)	(0.0372)	(0.0369)
GDP per capita	-3.548	-4.247	1.971	1.834	-3.728	-4.836
	(2.980)	(3.131)	(3.995)	(4.061)	(3.474)	(3.588)
Urban population %	-0.377	-0.398	-0.943	-0.951	1.045	0.942
	(0.496)	(0.486)	(0.743)	(0.729)	(0.950)	(0.950)
Population density	-0.629	0.421	-11.59	-11.86	22.10	22.95
	(13.72)	(13.85)	(15.07)	(14.82)	(20.28)	(20.97)
4G spectrum holdings	0.00378	0.00296	-0.00622	-0.00649	0.00605	0.00475
	(0.00794)	(0.00823)	(0.0253)	(0.0255)	(0.00808)	(0.00841)
QoS obligation	0.114	0.348	-1.607	-1.559	0.739	0.944
	(1.423)	(1.451)	(1.143)	(1.197)	(2.176)	(1.966)
Constant	81.27	87.16	71.40	77.29	-137.3	-116.5
	(76.41)	(77.56)	(87.60)	(81.27)	(137.6)	(148.1)
Country FE	yes	yes	yes	yes	yes	yes
Time FE	yes	yes	yes	yes	yes	yes
Observations	3,014	3,014	1,052	1,052	1,962	1,962
R-squared	0.329	0.330	0.420	0.420	0.270	0.273

Cluster-robust standard errors in parentheses

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

Figure A1.13

INSTRUMENTAL VARIABLE REGRESSION RESULTS USING LOG OF $PPP/MHZ/POP/LICENCE YEAR

4G upload speeds (Mbps)

	All countries		Developing		Developed	
	First stage	Second stage	First stage	Second stage	First stage	Second stage
Instruments						
Short-term debt	0.0365***		0.0454***			
	(0.00754)		(0.00831)			
Non-auction assignment	-0.379***				-0.391***	
	(0.0760)				(0.0746)	
Spectrum price in region	0.375*				0.0678	
	(0.194)				(0.254)	
Reserve price in region	0.110				0.372**	
	(0.101)				(0.184)	
Spectrum price						
Average effect		-3.872***		1.589		-6.618***
		(0.845)		(1.332)		(1.473)
Controls						
HHI	0.795***	6.674***	0.863***	2.194	1.056***	10.69***
	(0.264)	(1.992)	(0.308)	(2.914)	(0.349)	(3.289)
Market Share	0.00758***	0.0143	0.00982***	-0.0312*	0.0120***	0.0879***
	(0.00162)	(0.0129)	(0.00171)	(0.0163)	(0.00229)	(0.0261)
GDP per capita	-3.171***	-18.14***	0.250	1.860	-4.476***	-36.01***
	(0.489)	(4.218)	(1.094)	(5.052)	(0.487)	(7.899)
Urban population %	-0.00267	0.178	0.0350	-1.052**	-0.0885	0.514
	(0.0460)	(0.374)	(0.0488)	(0.475)	(0.102)	(0.865)
Population density	0.370	5.536	-1.522	-5.464	2.445	37.05
	(1.434)	(12.53)	(2.119)	(17.80)	(2.311)	(23.49)
4G spectrum holdings	0.00230***	0.0135***	0.00146	-0.0107	0.000836*	0.0120***
	(0.000398)	(0.00379)	(0.000929)	(0.00808)	(0.000438)	(0.00424)
QoS obligation	1.273***	5.533***	0.145*	-1.898***	1.799***	13.28***
	(0.0964)	(1.274)	(0.0740)	(0.732)	(0.126)	(3.035)
Constant	12.84*	48.07	-8.875	34.70	30.77**	80.19
	(6.770)	(61.23)	(13.91)	(85.37)	(15.41)	(155.7)
Country FE	yes	yes	yes	yes	yes	yes
Time FE	yes	yes	yes	yes	yes	yes
Observations	2,756		1,011		1,870	
Under identification p-value[1]	0.000		0.000		0.000	
Weak identification p-value[2]	0.000		0.000		0.000	
Weak identification F-Statistic[3]	17.680		29.85		12.400	
Overidentification p-value[4]	0.211		N/A		0.439	
Endogeneity p-value[5]	0.000		0.221		0.000	

Cluster-robust standard errors in parentheses

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

1. Reports the p-value of the Kleibergen-Paap rk LM statistic. Null hypothesis is that the model is underidentified.
2. Reports the p-value of the Sanderson-Windmeijer statistic. Null hypothesis is that the model is weakly identified.
3. Reports the Kleibergen-Paap Wald rk F-statistic for weak identification.
4. Reports the p-value of the Hansen's J statistic where more than one instrument is used. Joint null hypothesis is that the instruments are valid and not correlated with the error term.
5. Reports the p-value of the endogeneity test (C statistic). Null hypothesis is that the endogenous regressors are in fact exogenous.

A1.1.4 4G latencies

Figure A1.14

OLS REGRESSION RESULTS USING CPR

4G latencies (ms)

	All countries		Developing		Developed	
	(1)	(2)	(3)	(4)	(5)	(6)
Spectrum price						
Average effect	0.0148		0.847		-11.12	
	(0.750)		(0.918)		(12.84)	
Impact in first year		-1.572*		-0.880		-0.334
		(0.816)		(0.825)		(11.61)
Impact in second year		0.0222		0.736		-12.58
		(0.639)		(0.948)		(13.08)
Impact after two years		0.841		1.869		-13.68
		(1.249)		(1.367)		(14.79)
Controls						
HHI	-10.53	-10.52	-65.25*	-65.62*	16.02**	15.99**
	(16.43)	(16.15)	(35.72)	(34.73)	(7.630)	(7.469)
Market share	-0.0445	-0.0448	0.0915	0.0930	-0.288	-0.287
	(0.154)	(0.153)	(0.228)	(0.226)	(0.176)	(0.177)
GDP per capita	9.386	9.703	36.77	38.12	-11.69	-10.89
	(15.97)	(15.92)	(36.91)	(36.71)	(16.28)	(16.20)
Urban population %	-1.864	-1.869	0.00374	0.0494	-1.849	-1.744
	(2.388)	(2.294)	(4.229)	(3.988)	(4.145)	(4.117)
Population density	-15.65	-15.31	92.81	97.13	-37.45	-33.79
	(86.98)	(86.60)	(168.0)	(167.5)	(82.18)	(83.25)
4G spectrum holdings	-0.00429	-0.00390	0.0274	0.0281	0.00328	0.00407
	(0.0280)	(0.0279)	(0.0747)	(0.0745)	(0.0193)	(0.0195)
QoS obligation	5.820	5.776	13.96	13.85	2.221	2.119
	(5.627)	(5.608)	(10.88)	(10.86)	(2.177)	(2.134)
Constant	244.4	240.0	-164.7	-195.8	371.0	336.8
	(537.7)	(534.0)	(1,026)	(1,024)	(590.0)	(590.9)
Country FE	yes	yes	yes	yes	yes	yes
Time FE	yes	yes	yes	yes	yes	yes
Observations	2,912	2,912	1,032	1,032	1,880	1,880
R-squared	0.386	0.387	0.441	0.443	0.318	0.318

Cluster-robust standard errors in parentheses

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

Figure A1.15

ROBUSTNESS CHECKS USING CPR

4G latencies (ms)

	(1)	(2)	(3)	(4)	(5)
	All countries				
Average effect	0.0148	0.0148	-0.0664	0.00265	-0.0193
Impact in first year	-1.572*	-1.572	-1.141**	-0.0199*	-0.400
Impact in second year	0.0222	0.0222	0.650	0.00885	0.188
Impact after two years	0.841	0.841	1.031	0.00919	0.142
4G spectrum holdings	-0.00429	-0.00429	-0.00453	-0.000284	-0.00418
	Developing countries				
Average effect	0.847	0.847	-0.396	0.0161	0.239
Impact in first year	-0.880	-0.880	-1.365***	-0.00979	-0.221
Impact in second year	0.736	0.736	0.465	0.0212	0.376
Impact after two years	1.869	1.869	1.169	0.0258	0.843
4G spectrum holdings	0.0274	0.0274	0.0173	0.00001	0.0310
	Developed countries				
Average effect	-11.12	-11.12	-8.506	-0.0883	2.650
Impact in first year	-0.334	-0.334	3.762	0.0973	5.453
Impact in second year	-12.58	-12.58	-10.87	-0.0209	5.918
Impact after two years	-13.68	-13.68	-17.95	-0.178	-4.158
4G spectrum holdings	0.00328	0.00328	-0.00472	-0.000146	0.00173
Standard error clusters	Country	Operator	Operator	Country	Country
Country or operator FE	Country	Country	Operator	Country	Country
Time FE	Yes	Yes	Yes	Yes	Yes
Log transformation of 4G upload speeds	No	No	No	Yes	No
Current or Future Revenues	Current	Current	Current	Current	Future

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

Figure A1.16

OLS REGRESSION RESULTS USING LOG OF $PPP/MHZ/POP/LICENCE YEAR

4G latencies (ms)

	All countries		Developing		Developed	
	(1)	(2)	(3)	(4)	(5)	(6)
Spectrum price						
Average effect	-0.420		-0.0332		-0.139	
	(0.851)		(1.181)		(0.685)	
Impact in first year		-0.103		-0.332		0.133
		(0.155)		(0.224)		(0.104)
Impact in second year		-0.0183		-0.230		0.207
		(0.149)		(0.172)		(0.140)
Impact after two years		-0.148		-0.111		0.0120
		(0.128)		(0.224)		(0.102)
Controls						
HHI	-8.274	-8.453	-66.66*	-65.16*	17.58**	14.48*
	(15.64)	(15.20)	(34.20)	(33.79)	(8.417)	(8.199)
Market share	-0.0271	-0.0264	0.0628	0.0638	-0.194	-0.191
	(0.132)	(0.129)	(0.197)	(0.191)	(0.137)	(0.134)
GDP per capita	6.107	7.759	36.96	35.96	-12.58	-12.63
	(16.98)	(16.22)	(36.31)	(35.72)	(16.62)	(15.58)
Urban population %	-1.560	-1.505	0.196	0.570	-1.197	-1.476
	(2.343)	(2.378)	(4.205)	(3.971)	(4.064)	(4.007)
Population density	-15.32	-12.49	87.46	85.83	-35.18	-36.41
	(86.26)	(86.05)	(166.2)	(164.6)	(83.27)	(85.43)
4G spectrum holdings	-0.00658	-0.00851	0.0319	0.0376	-0.00402	-0.00997
	(0.0261)	(0.0263)	(0.0703)	(0.0722)	(0.0182)	(0.0178)
QoS obligation	6.034	5.573	13.82	13.24	2.925	2.198
	(5.381)	(4.954)	(10.44)	(9.946)	(2.133)	(2.226)
Constant	233.9	200.5	-142.3	-169.1	302.6	361.4
	(529.2)	(530.9)	(1,017)	(1,002)	(592.8)	(591.4)
Country FE	yes	yes	yes	yes	yes	yes
Time FE	yes	yes	yes	yes	yes	yes
Observations	3,014	3,014	1,052	1,052	1,962	1,962
R-squared	0.381	0.381	0.432	0.434	0.316	0.317

Cluster-robust standard errors in parentheses

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

Figure A1.17

INSTRUMENTAL VARIABLE REGRESSION RESULTS USING LOG OF $PPP/MHZ/POP/LICENCE YEAR

4G latencies (ms)

	All countries		Developing		Developed	
	First stage	Second stage	First stage	Second stage	First stage	Second stage
Instruments						
Short-term debt	0.0365***		0.0454***			
	(0.00754)		(0.00831)			
Non-auction assignment	-0.379***				-0.391***	
	(0.0760)				(0.0746)	
Spectrum price in region	0.375*				0.0678	
	(0.194)				(0.254)	
Reserve price in region	0.110				0.372**	
	(0.101)				(0.184)	
Spectrum price						
Average effect		-0.831		-9.988		-5.398
		(4.736)		(7.311)		(6.207)
Controls						
HHI	0.795***	-8.898	0.863***	-55.19***	1.056***	17.22*
	(0.264)	(9.381)	(0.308)	(20.69)	(0.349)	(9.583)
Market Share	0.00758***	-0.00899	0.00982***	0.143	0.0120***	-0.167
	(0.00162)	(0.0766)	(0.00171)	(0.0904)	(0.00229)	(0.114)
GDP per capita	-3.171***	-2.834	0.250	30.32	-4.476***	-37.99
	(0.489)	(19.12)	(1.094)	(31.32)	(0.487)	(33.64)
Urban population %	-0.00267	-1.679	0.0350	1.090	-0.0885	-2.031
	(0.0460)	(1.756)	(0.0488)	(2.563)	(0.102)	(4.150)
Population density	0.370	-65.56	-1.522	32.37	2.445	-7.227
	(1.434)	(62.06)	(2.119)	(117.7)	(2.311)	(53.06)
4G spectrum holdings	0.00230***	-0.0163	0.00146	0.0550	0.000836*	0.00175
	(0.000398)	(0.0143)	(0.000929)	(0.0348)	(0.000438)	(0.0132)
QoS obligation	1.273***	6.858	0.145*	15.09***	1.799***	13.00
	(0.0964)	(5.846)	(0.0740)	(4.157)	(0.126)	(11.34)
Constant	12.84*	429.3	-8.875	63.36	30.77**	448.9
	(6.770)	(293.4)	(13.91)	(654.4)	(15.41)	(408.3)
Country FE	yes	yes	yes	yes	yes	yes
Time FE	yes	yes	yes	yes	yes	yes
Observations	2,756		1,011		1,870	
Under identification p-value[1]	0.000		0.000		0.000	
Weak identification p-value[2]	0.000		0.000		0.000	
Weak identification F-Statistic[3]	17.680		29.85		12.400	
Overidentification p-value[4]	0.263		N/A		0.460	
Endogeneity p-value[5]	0.946		0.158		0.408	

Cluster-robust standard errors in parentheses

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

1. Reports the p-value of the Kleibergen-Paap rk LM statistic. Null hypothesis is that the model is underidentified.
2. Reports the p-value of the Sanderson-Windmeijer statistic. Null hypothesis is that the model is weakly identified.
3. Reports the Kleibergen-Paap Wald rk F-statistic for weak identification.
4. Reports the p-value of the Hansen's J statistic where more than one instrument is used. Joint null hypothesis is that the instruments are valid and not correlated with the error term.
5. Reports the p-value of the endogeneity test (C statistic). Null hypothesis is that the endogenous regressors are in fact exogenous.

A1.2 3G networks

A1.2.1 3G coverage

Figure A1.18

OLS REGRESSION RESULTS USING CPR

3G coverage (percentage of population)

	All countries		Developing		Developed	
	(1)	(2)	(3)	(4)	(5)	(6)
Spectrum price						
Average effect	-0.0447***		-0.0472***		-1.128	
	(0.0107)		(0.0118)		(51.33)	
Impact in first year		-0.0290***		-0.0309***		-34.15
		(0.0101)		(0.00955)		(33.71)
Impact in second year		-0.123***		-0.128***		-36.03
		(0.0221)		(0.0257)		(45.58)
Impact after two years		-0.0172		-0.0183		27.89
		(0.0744)		(0.0744)		(40.21)
Controls						
HHI	-11.65*	-11.53*	-9.101	-8.920	-20.32**	-17.84*
	(6.201)	(6.216)	(7.009)	(7.010)	(7.867)	(8.876)
Market share	0.192**	0.193**	0.220**	0.221**	0.147*	0.153*
	(0.0886)	(0.0885)	(0.103)	(0.103)	(0.0734)	(0.0765)
GDP per capita	0.789	0.474	-3.454	-3.958	10.27	3.863
	(26.31)	(26.51)	(39.55)	(39.97)	(25.67)	(21.91)
Urban population %	0.0658	0.0555	-2.027	-2.051	10.87***	11.87***
	(1.183)	(1.185)	(1.812)	(1.821)	(3.530)	(4.053)
Population density	95.68	95.61	78.45	78.23	103.4*	86.72
	(77.55)	(77.46)	(104.9)	(104.8)	(58.51)	(54.27)
3G spectrum holdings	-0.0108	-0.0109	-0.00422	-0.00427	-0.0114	-0.0100
	(0.0335)	(0.0336)	(0.0378)	(0.0378)	(0.0894)	(0.0931)
3G spectrum: 1-2 years	14.04***	14.07***	15.00***	15.03***	2.900	6.077
	(3.623)	(3.614)	(3.442)	(3.432)	(4.221)	(6.731)
3G spectrum: 2+ years	20.28***	20.25***	22.61***	22.57***	-12.74	-22.55***
	(6.446)	(6.450)	(6.272)	(6.287)	(11.07)	(7.542)
Smartphone adoption	6.547	6.573	12.73	12.86	13.56	14.49
	(12.65)	(12.66)	(19.20)	(19.25)	(9.178)	(8.571)
Coverage obligation	-6.280*	-6.292*	-6.807	-6.824	-2.023	-1.370
	(3.726)	(3.700)	(5.107)	(5.074)	(1.355)	(1.335)
Constant	-267.8	-264.9	-71.27	-65.82	-1,114**	-1,068**
	(408.1)	(406.8)	(583.7)	(582.4)	(406.5)	(368.6)
Country FE	yes	yes	yes	yes	yes	yes
Time FE	yes	yes	yes	yes	yes	yes
Observations	1,622	1,622	1,119	1,119	503	503
R-squared	0.781	0.781	0.776	0.776	0.746	0.760

Cluster-robust standard errors in parentheses

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

Figure A1.19

ROBUSTNESS CHECKS USING CPR

	3G coverage (percentage of population)				
	(1)	(2)	(3)	(4)	(5)
	All countries				
Average effect	-0.0447***	-0.0447**	0.0243***	-0.00295***	-0.0195***
Impact in first year	-0.0290***	-0.0290***	0.00433	-0.00114	-0.0151***
Impact in second year	-0.123***	-0.123***	0.0429***	-0.00707***	-0.0726***
Impact after two years	-0.0172	-0.0172	0.103***	-0.00537	0.00392
3G spectrum holdings	-0.0108	-0.0108	-0.0425	-0.00339	-0.0106
3G spectrum: 1-2 years	14.04***	14.04***	13.97***	1.590***	14.03***
3G spectrum: 2+ years	20.28***	20.28***	20.76***	1.825***	20.28***
	Developing countries				
Average effect	-0.0472***	-0.0472**	0.0237***	-0.00321***	-0.0207***
Impact in first year	-0.0309***	-0.0309***	0.00367	-0.00115	-0.0155***
Impact in second year	-0.128***	-0.128***	0.0451***	-0.00785***	-0.0752***
Impact after two years	-0.0183	-0.0183	0.105***	-0.00636	-0.000241
3G spectrum holdings	-0.00422	-0.00422	-0.0708	-0.00336	-0.00393
3G spectrum: 1-2 years	15.00***	15.00***	14.47***	1.590***	15.00***
3G spectrum: 2+ years	22.61***	22.61***	20.78***	1.920***	22.62***
	Developed countries				
Average effect	-1.128	-1.128	-17.30	1.851	0.0880
Impact in first year	-34.15	-34.15	-18.56	-0.376	-13.98
Impact in second year	-36.03	-36.03	-12.17	0.769	-4.326
Impact after two years	27.89	27.89	23.58	2.197	21.30
3G spectrum holdings	-0.0114	-0.0114	-0.0361	-0.00120	-0.0114
3G spectrum: 1-2 years	2.900	2.900	4.226**	0.0710	2.836
3G spectrum: 2+ years	-12.74	-12.74	8.972***	-0.313	-12.47***
Standard error clusters	Country	Operator	Operator	Country	Country
Country or operator FE	Country	Country	Operator	Country	Country
Time FE	Yes	Yes	Yes	Yes	Yes
Logit transformation of 4G coverage	No	No	No	Yes	No
Current or Future Revenues	Current	Current	Current	Current	Future

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

Figure A1.20

OLS REGRESSION RESULTS USING LOG OF $PPP/MHZ/POP/LICENCE YEAR

	3G coverage (percentage of population)					
	All countries		Developing		Developed	
	(1)	(2)	(3)	(4)	(5)	(6)
Spectrum price						
Average effect	1.608		2.489		-0.373	
	(1.616)		(1.974)		(2.825)	
Impact in first year		0.306*		0.358*		0.0282
		(0.171)		(0.207)		(0.219)
Impact in second year		0.296*		0.273		0.137
		(0.162)		(0.194)		(0.256)
Impact after two years		-0.0126		-0.132		0.165
		(0.159)		(0.214)		(0.183)
Controls						
HHI	-16.80**	-19.07***	-13.95*	-15.64***	-41.98***	-41.80***
	(6.813)	(5.931)	(6.977)	(5.442)	(11.25)	(12.13)
Market share	0.205**	0.207**	0.199**	0.206**	0.310***	0.309***
	(0.0795)	(0.0775)	(0.0947)	(0.0942)	(0.0701)	(0.0708)
GDP per capita	7.293	8.056	3.176	14.42	33.17	31.56
	(26.92)	(25.53)	(41.27)	(39.38)	(25.52)	(20.89)
Urban population %	-0.0955	-0.570	-1.551	-2.010	11.30**	12.11**
	(0.982)	(0.998)	(1.444)	(1.349)	(4.290)	(5.151)
Population density	114.4	98.55	95.14	74.24	167.9*	172.8**
	(76.44)	(71.69)	(101.2)	(91.89)	(81.86)	(73.20)
3G spectrum holdings	-0.00362	-0.00924	0.0138	0.0101	-0.0418	-0.0395
	(0.0328)	(0.0329)	(0.0395)	(0.0396)	(0.0701)	(0.0751)
3G spectrum: 1-2 years	12.17***	12.16***	13.65***	14.38***	-0.122	-1.058
	(3.635)	(3.402)	(3.496)	(3.014)	(6.456)	(6.923)
3G spectrum: 2+ years	17.89***	19.87***	19.94***	23.39***	-1.500	-1.978
	(6.039)	(5.715)	(6.511)	(5.855)	(11.61)	(12.81)
Smartphone adoption	4.683	4.214	8.812	5.941	12.03	13.71
	(12.60)	(11.97)	(19.77)	(17.59)	(10.04)	(9.704)
Coverage obligation	-5.544	-5.595	-6.820	-6.830	-0.0931	0.373
	(3.474)	(3.506)	(5.038)	(4.976)	(1.987)	(2.588)
Constant	-353.8	-246.0	-180.6	-158.9	-1,500**	-1,564**
	(383.1)	(342.4)	(533.0)	(481.8)	(623.6)	(562.5)
Country FE	yes	yes	yes	yes	yes	yes
Time FE	yes	yes	yes	yes	yes	yes
Observations	1,724	1,724	1,178	1,178	546	546
R-squared	0.790	0.793	0.772	0.776	0.855	0.856

Cluster-robust standard errors in parentheses

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

Figure A1.21

INSTRUMENTAL VARIABLE REGRESSION RESULTS USING LOG OF $PPP/MHZ/POP/LICENCE YEAR

	3G coverage (percentage of population)					
	All countries		Developing		Developed	
	(1)	(2)	(3)	(4)	(5)	(6)
Instruments						
Short-term debt	0.0276***		0.0277***			
	(0.00798)		(0.00775)			
Non-auction assignment	-0.468***				-0.232*	
	(0.134)				(0.128)	
Spectrum price in region	0.424*				0.562*	
	(0.238)				(0.328)	
Reserve price in region	-0.117				-0.145**	
	(0.0857)				(0.0700)	
Spectrum price						
Average effect		-4.721**		5.023		7.712
		(2.179)		(5.827)		(5.302)
Controls						
HHI	0.629**	-12.37*	1.564***	-16.05	-1.710***	-22.75*
	(0.256)	(7.103)	(0.177)	(11.83)	(0.469)	(11.78)
Market Share	0.00388**	0.189***	0.00702***	0.283***	-0.000140	0.216***
	(0.00178)	(0.0325)	(0.00137)	(0.0461)	(0.00431)	(0.0460)
GDP per capita	-2.710***	8.541	-0.293	5.385	-2.811***	59.11***
	(0.610)	(12.50)	(0.876)	(23.05)	(0.448)	(15.72)
Urban population %	0.0160	1.248*	0.0948***	-2.053	-0.857***	18.62***
	(0.0332)	(0.748)	(0.0321)	(1.339)	(0.233)	(6.083)
Population density	-7.101***	97.44***	1.866	70.61	-1.705	85.57***
	(1.727)	(35.63)	(1.380)	(54.52)	(2.468)	(28.13)
3G spectrum holdings	-0.00363***	-0.0708***	-0.00462***	0.00418	0.000466	-0.00935
	(0.000808)	(0.0143)	(0.000907)	(0.0343)	(0.00125)	(0.0228)
3G spectrum: 1-2 years	-0.0312	13.59***	0.0120	13.76***	-0.275	10.74*
	(0.153)	(4.294)	(0.0865)	(3.618)	(0.202)	(5.774)
3G spectrum: 2+ years	-0.0539	18.64***	0.0254	20.51***	-1.271***	16.33**
	(0.150)	(3.905)	(0.0876)	(3.561)	(0.220)	(8.195)
Smartphone adoption	0.455	19.03***	1.249***	1.965	-0.530	23.81***
	(0.299)	(5.751)	(0.316)	(12.54)	(0.600)	(7.579)
Coverage obligation	0.328***	-7.959***	-0.0562	-6.573***	0.649***	-8.746**
	(0.0825)	(1.674)	(0.0585)	(1.628)	(0.101)	(3.695)
Constant	38.33***	-387.7**	-24.71**	-110.3	134.1***	-2,661***
	(9.294)	(191.5)	(10.60)	(341.4)	(30.55)	(836.8)
Country FE	yes	yes	yes	yes	yes	yes
Time FE	yes	yes	yes	yes	yes	yes
Observations	1,203		999		495	
Under identification p-value[1]	0.000		0.000		0.016	
Weak identification p-value[2]	0.000		0.000		0.022	
Weak identification F-Statistic[3]	7.339		12.81		3.251	
Overidentification p-value[4]	0.223		N/A		0.032	
Endogeneity p-value[5]	0.011		0.566		0.040	

Cluster-robust standard errors in parentheses

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

1. Reports the p-value of the Kleibergen-Paap rk LM statistic. Null hypothesis is that the model is underidentified.
2. Reports the p-value of the Sanderson-Windmeijer statistic. Null hypothesis is that the model is weakly identified.
3. Reports the Kleibergen-Paap Wald rk F-statistic for weak identification.
4. Reports the p-value of the Hansen's J statistic where more than one instrument is used. Joint null hypothesis is that the instruments are valid and not correlated with the error term.
5. Reports the p-value of the endogeneity test (C statistic). Null hypothesis is that the endogenous regressors are in fact exogenous.

A1.2.2 3G download speeds

Figure A1.22

OLS REGRESSION RESULTS USING CPR

3G download speeds (Mbps)

	All countries		Developing		Developed	
	(1)	(2)	(3)	(4)	(5)	(6)
Spectrum price						
Average effect	-0.00417***		-0.00382***		-5.247*	
	(0.000601)		(0.000710)		(3.048)	
Impact in first year		0.00104		-0.000111		-2.334
		(0.000913)		(0.000731)		(1.912)
Impact in second year		-0.0120***		-0.0109***		-5.732**
		(0.00147)		(0.00172)		(2.809)
Impact after two years		-0.0203***		-0.0135***		-5.049
		(0.00520)		(0.00432)		(3.399)
Controls						
HHI	1.865	1.860	2.628**	2.633**	0.920	0.873
	(1.354)	(1.351)	(1.093)	(1.092)	(2.351)	(2.345)
Market share	0.0125*	0.0125*	0.0147	0.0148	0.00332	0.00438
	(0.00671)	(0.00670)	(0.00868)	(0.00868)	(0.0115)	(0.0114)
GDP per capita	-4.661***	-4.702***	-1.526	-1.605	-5.115***	-4.816***
	(1.560)	(1.566)	(2.438)	(2.439)	(1.550)	(1.614)
Urban population %	-0.455***	-0.454***	-0.349**	-0.352**	-0.313	-0.287
	(0.137)	(0.137)	(0.165)	(0.164)	(0.351)	(0.355)
Population density	-7.665	-7.648	0.220	0.140	-6.452	-5.747
	(5.353)	(5.343)	(7.625)	(7.622)	(6.971)	(6.926)
3G spectrum holdings	0.00861**	0.00857**	0.00433	0.00428	0.00988*	0.0102*
	(0.00395)	(0.00395)	(0.00276)	(0.00277)	(0.00570)	(0.00578)
QoS obligation	-0.0282	-0.0305	-0.585**	-0.589**	0.353	0.311
	(0.433)	(0.433)	(0.257)	(0.256)	(0.617)	(0.615)
Constant	103.4***	103.8***	16.46	17.65	107.7*	99.44*
	(32.64)	(32.64)	(46.28)	(46.30)	(54.74)	(54.15)
Country FE	yes	yes	yes	yes	yes	yes
Time FE	yes	yes	yes	yes	yes	yes
Observations	3,568	3,568	1,468	1,468	2,100	2,100
R-squared	0.745	0.746	0.702	0.703	0.754	0.754

Cluster-robust standard errors in parentheses

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

Figure A1.23

ROBUSTNESS CHECKS USING CPR

	3G download speeds (Mbps)				
	(1)	(2)	(3)	(4)	(5)
	All countries				
Average effect	-0.00417***	-0.00417***	-0.00171***	-0.00181***	-0.00212***
Impact in first year	0.00104	0.00104	0.00140	-0.000788***	0.000369
Impact in second year	-0.0120***	-0.0120***	-0.00960***	-0.00566***	-0.00756***
Impact after two years	-0.0203***	-0.0203***	-0.0185***	-0.00236**	-0.0117***
3G spectrum holdings	0.00861**	0.00861***	0.0113***	0.00140*	0.00817**
	Developing countries				
Average effect	-0.00382***	-0.00382***	-0.000656**	-0.00190***	-0.00185***
Impact in first year	-0.000111	-0.000111	0.00111*	-0.000862***	-0.00006
Impact in second year	-0.0109***	-0.0109***	-0.00555***	-0.00579***	-0.00650***
Impact after two years	-0.0135***	-0.0135***	-0.0108***	-0.00243**	-0.00800***
3G spectrum holdings	0.00433	0.00433	0.0108	0.000905	0.00436
	Developed countries				
Average effect	-5.247*	-5.247**	-0.0924	-0.801	-1.132
Impact in first year	-2.334	-2.334	2.271	-0.566	-0.498
Impact in second year	-5.732**	-5.732**	0.168	-0.946**	-2.162
Impact after two years	-5.049	-5.049*	0.353	-0.659	-1.246
3G spectrum holdings	0.00988*	0.00988**	0.00773*	0.00172	0.00919
Standard error clusters	Country	Operator	Operator	Country	Country
Country or operator FE	Country	Country	Operator	Country	Country
Time FE	Yes	Yes	Yes	Yes	Yes
Log transformation of 4G download speeds	No	No	No	Yes	No
Current or Future Revenues	Current	Current	Current	Current	Future

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

Figure A1.24

OLS REGRESSION RESULTS USING LOG OF $PPP/MHZ/POP/LICENCE YEAR

3G download speeds (Mbps)

	All countries		Developing		Developed	
	(1)	(2)	(3)	(4)	(5)	(6)
Spectrum price						
Average effect	0.138*		0.254		0.0360	
	(0.0764)		(0.188)		(0.104)	
Impact in first year		0.0338**		0.0566***		0.00574
		(0.0144)		(0.0196)		(0.0166)
Impact in second year		0.0249		0.0636***		-0.0141
		(0.0155)		(0.0190)		(0.0157)
Impact after two years		0.0165		0.0262		-0.00183
		(0.0132)		(0.0213)		(0.0127)
Controls						
HHI	1.818	1.742	1.984**	1.700**	1.328	1.457
	(1.206)	(1.153)	(0.953)	(0.775)	(2.120)	(2.097)
Market share	0.0144**	0.0149**	0.0135	0.0151*	0.0139	0.0141
	(0.00622)	(0.00619)	(0.00945)	(0.00805)	(0.00934)	(0.00941)
GDP per capita	-4.259***	-4.763***	-1.285	-1.350	-4.304***	-4.474***
	(1.541)	(1.493)	(2.328)	(2.166)	(1.511)	(1.513)
Urban population %	-0.455***	-0.483***	-0.432***	-0.492***	-0.112	-0.116
	(0.138)	(0.138)	(0.145)	(0.140)	(0.351)	(0.352)
Population density	-7.551	-8.358*	1.650	0.603	-8.441	-8.534
	(5.244)	(4.972)	(7.243)	(6.860)	(6.415)	(6.436)
3G spectrum holdings	0.00779*	0.00858**	0.00543*	0.00578**	0.00874	0.00909
	(0.00414)	(0.00407)	(0.00285)	(0.00255)	(0.00612)	(0.00587)
QoS obligation	-0.334	-0.207	-0.530**	-0.432	-0.0880	-0.0223
	(0.426)	(0.399)	(0.243)	(0.277)	(0.671)	(0.578)
Constant	100.1***	111.7***	19.43	30.94	89.59*	90.80*
	(32.92)	(31.01)	(44.70)	(40.09)	(49.69)	(49.43)
Country FE	yes	yes	yes	yes	yes	yes
Time FE	yes	yes	yes	yes	yes	yes
Observations	3,716	3,716	1,511	1,511	2,205	2,205
R-squared	0.739	0.739	0.699	0.706	0.739	0.740

Cluster-robust standard errors in parentheses

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

Figure A1.25

INSTRUMENTAL VARIABLE REGRESSION RESULTS USING LOG OF $PPP/MHZ/POP/LICENCE YEAR

3G download speeds (Mbps)

	All countries		Developing		Developed	
	First stage	Second stage	First stage	Second stage	First stage	Second stage
Instruments						
Short-term debt	0.0355***		0.0364***			
	(0.00759)		(0.00729)			
Non-auction assignment	-0.528***				-0.489***	
	(0.0650)				(0.0625)	
Spectrum price in region	0.232				-0.0654	
	(0.163)				(0.169)	
Reserve price in region	-0.0536				0.217*	
	(0.0840)				(0.121)	
Spectrum price						
Average effect		-0.0322		-1.769***		0.0427
		(0.187)		(0.526)		(0.223)
Impact in second year						-0.310***
						(0.0714)
Controls						
HHI	0.729***	0.984**	1.096***	4.340***	0.597*	0.709
	(0.218)	(0.442)	(0.178)	(0.895)	(0.316)	(0.639)
Market Share	0.00899***	0.0119***	0.0139***	0.0425***	0.00673***	0.00908***
	(0.00157)	(0.00298)	(0.00152)	(0.00811)	(0.00205)	(0.00339)
GDP per capita	-3.534***	-4.173***	-0.359	-1.228	-3.818***	-4.020***
	(0.460)	(0.969)	(0.908)	(2.072)	(0.440)	(1.163)
Urban population %	0.0382	-0.589***	0.0972***	-0.262*	0.0458	-0.239*
	(0.0394)	(0.0722)	(0.0359)	(0.153)	(0.112)	(0.125)
Population density	0.665	-15.16***	0.824	6.058*	5.449***	-10.00***
	(1.255)	(2.690)	(1.225)	(3.474)	(1.940)	(3.411)
3G spectrum holdings	0.00520***	0.00991***	-0.00382***	-0.00295	0.00812***	0.00999***
	(0.000711)	(0.00162)	(0.000791)	(0.00306)	(0.000769)	(0.00239)
QoS obligation	1.411***	-0.201	0.101	-0.447**	1.956***	-0.0770
	(0.0874)	(0.303)	(0.0653)	(0.195)	(0.106)	(0.491)
Constant	12.47**	97.76***	-16.81	-53.43**	4.200	101.4***
	(6.134)	(13.96)	(10.39)	(26.68)	(15.23)	(22.71)
Country FE	yes	yes	yes	yes	yes	yes
Time FE	yes	yes	yes	yes	yes	yes
Observations	3,082		1,364		2,075	
Under identification p-value[1]	0.000		0.000		0.000	
Weak identification p-value[2]	0.000		0.000		0.000	
Weak identification F-Statistic[3]	25.730		24.92		20.500	
Overidentification p-value[4]	0.000		N/A		0.000	
Endogeneity p-value[5]	0.696		0.000		0.501	

Cluster-robust standard errors in parentheses

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

1. Reports the p-value of the Kleibergen-Paap rk LM statistic. Null hypothesis is that the model is underidentified.
2. Reports the p-value of the Sanderson-Windmeijer statistic. Null hypothesis is that the model is weakly identified.
3. Reports the Kleibergen-Paap Wald rk F-statistic for weak identification.
4. Reports the p-value of the Hansen's J statistic where more than one instrument is used. Joint null hypothesis is that the instruments are valid and not correlated with the error term.
5. Reports the p-value of the endogeneity test (C statistic). Null hypothesis is that the endogenous regressors are in fact exogenous.

A1.2.3 3G upload speeds

Figure A1.26

OLS REGRESSION RESULTS USING CPR

3G upload speeds (Mbps)

	All countries		Developing		Developed	
	(1)	(2)	(3)	(4)	(5)	(6)
Spectrum price						
Average effect	-0.000413***		-0.000580***		-0.259	
	(0.000145)		(0.000198)		(0.447)	
Impact in first year		0.000156		-0.00006		-0.330
		(0.000161)		(0.000194)		(0.363)
Impact in second year		-0.000980***		-0.00142***		-0.545
		(0.000363)		(0.000459)		(0.437)
Impact after two years		-0.00240***		-0.00197**		-0.0888
		(0.000778)		(0.000910)		(0.523)
Controls						
HHI	0.207	0.206	0.776**	0.776**	-0.281	-0.267
	(0.270)	(0.270)	(0.287)	(0.287)	(0.355)	(0.355)
Market share	-0.000585	-0.000586	0.00210	0.00211	-0.00364	-0.00370
	(0.00212)	(0.00212)	(0.00286)	(0.00286)	(0.00247)	(0.00244)
GDP per capita	-1.022***	-1.026***	-0.315	-0.326	-0.999***	-1.004***
	(0.296)	(0.295)	(0.613)	(0.610)	(0.233)	(0.227)
Urban population %	-0.0393	-0.0392	-0.0641	-0.0644	-0.0913	-0.0917
	(0.0315)	(0.0315)	(0.0506)	(0.0505)	(0.0741)	(0.0729)
Population density	-0.907	-0.904	-0.750	-0.761	-1.019	-1.046
	(1.120)	(1.119)	(1.598)	(1.596)	(1.182)	(1.168)
3G spectrum holdings	0.000506	0.000502	-0.000557	-0.000565	0.00120	0.00117
	(0.000827)	(0.000829)	(0.00137)	(0.00137)	(0.000965)	(0.000949)
QoS obligation	0.0396	0.0394	-0.228*	-0.228*	0.152*	0.155*
	(0.0810)	(0.0810)	(0.124)	(0.125)	(0.0775)	(0.0777)
Constant	16.89**	16.93**	4.846	5.012	26.46***	26.55***
	(6.832)	(6.822)	(9.049)	(9.026)	(8.931)	(8.658)
Country FE	yes	yes	yes	yes	yes	yes
Time FE	yes	yes	yes	yes	yes	yes
Observations	3,568	3,568	1,468	1,468	2,100	2,100
R-squared	0.718	0.718	0.679	0.679	0.746	0.747

Cluster-robust standard errors in parentheses

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

Figure A1.27

ROBUSTNESS CHECKS USING CPR

	3G upload speeds (Mbps)				
	(1)	(2)	(3)	(4)	(5)
	All countries				
Average effect	-0.000413***	-0.000413***	-0.000373***	-0.000726***	-0.000221***
Impact in first year	0.000156	0.000156	0.00005	-0.000196	0.00003
Impact in second year	-0.000980***	-0.000980***	-0.00127***	-0.00171***	-0.000657***
Impact after two years	-0.00240***	-0.00240***	-0.00241***	-0.00188***	-0.00125***
3G spectrum holdings	0.000506	0.000506	0.00119	-0.00003	0.000580
	Developing countries				
Average effect	-0.000580***	-0.000580***	-0.000336***	-0.000948***	-0.000297***
Impact in first year	0.00007	0.00007	0.00002	-0.000220	-0.00004
Impact in second year	-0.00142***	-0.00142***	-0.00129***	-0.00228***	-0.000870***
Impact after two years	-0.00197**	-0.00197***	-0.00211***	-0.00265***	-0.00120**
3G spectrum holdings	-0.000557	-0.000557	0.00246	-0.00109	-0.000554
	Developed countries				
Average effect	-0.259	-0.259	0.0445	-0.0302	-0.0741
Impact in first year	-0.330	-0.330	-0.0311	-0.249	-0.151
Impact in second year	-0.545	-0.545	-0.104	-0.329	-0.329
Impact after two years	-0.0888	-0.0888	0.229	0.0758	0.00194
3G spectrum holdings	0.00120	0.00120	0.00104	0.000738	0.00135
Standard error clusters	Country	Operator	Operator	Country	Country
Country or operator FE	Country	Country	Operator	Country	Country
Time FE	Yes	Yes	Yes	Yes	Yes
Log transformation of 4G upload speeds	No	No	No	Yes	No
Current or Future Revenues	Current	Current	Current	Current	Future

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

Figure A1.28

OLS REGRESSION RESULTS USING LOG OF $PPP/MHZ/POP/LICENCE YEAR

3G upload speeds (Mbps)

	All countries		Developing		Developed	
	(1)	(2)	(3)	(4)	(5)	(6)
Spectrum price						
Average effect	0.0581***		0.0683		0.0440***	
	(0.0177)		(0.0599)		(0.0138)	
Impact in first year		0.00781**		0.0154**		-0.00190
		(0.00375)		(0.00586)		(0.00275)
Impact in second year		0.0101**		0.0219***		-0.00398
		(0.00429)		(0.00610)		(0.00289)
Impact after two years		0.00822**		0.0133*		-0.000773
		(0.00397)		(0.00726)		(0.00294)
Controls						
HHI	0.109	0.109	0.539**	0.423**	-0.219	-0.0996
	(0.221)	(0.216)	(0.218)	(0.189)	(0.301)	(0.304)
Market share	-0.000211	9.39e-05	0.00188	0.00213	-0.00205	-0.00169
	(0.00194)	(0.00186)	(0.00321)	(0.00264)	(0.00232)	(0.00230)
GDP per capita	-0.826***	-1.060***	-0.167	-0.266	-0.802***	-0.983***
	(0.297)	(0.313)	(0.632)	(0.699)	(0.266)	(0.258)
Urban population %	-0.0502**	-0.0551**	-0.0903*	-0.101*	-0.0598	-0.0485
	(0.0248)	(0.0265)	(0.0465)	(0.0523)	(0.0747)	(0.0828)
Population density	-0.734	-0.995	0.00356	-0.237	-1.876	-1.592
	(1.114)	(1.069)	(1.510)	(1.493)	(1.245)	(1.289)
3G spectrum holdings	0.000507	0.000777	-0.000175	-0.000156	0.00101	0.00134
	(0.000790)	(0.000813)	(0.00140)	(0.00128)	(0.00101)	(0.000954)
QoS obligation	-0.0572	0.0124	-0.229*	-0.190	0.0191	0.121
	(0.0780)	(0.0727)	(0.122)	(0.119)	(0.0873)	(0.0760)
Constant	15.96**	19.89***	4.064	7.849	25.71***	24.10**
	(7.088)	(6.763)	(9.088)	(9.346)	(9.376)	(10.06)
Country FE	yes	yes	yes	yes	yes	yes
Time FE	yes	yes	yes	yes	yes	yes
Observations	3,716	3,716	1,511	1,511	2,205	2,205
R-squared	0.707	0.704	0.663	0.675	0.732	0.728

Cluster-robust standard errors in parentheses

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

Figure A1.29

INSTRUMENTAL VARIABLE REGRESSION RESULTS USING LOG OF $PPP/MHZ/POP/LICENCE YEAR

3G upload speeds (Mbps)

	All countries		Developing		Developed	
	First stage	Second stage	First stage	Second stage	First stage	Second stage
Instruments						
Short-term debt	0.0355***		0.0364***			
	(0.00759)		(0.00729)			
Non-auction assignment	-0.528***				-0.489***	
	(0.0650)				(0.0625)	
Spectrum price in region	0.232				-0.0654	
	(0.163)				(0.169)	
Reserve price in region	-0.0536				0.217*	
	(0.0840)				(0.121)	
Spectrum price						
Average effect		-0.0249		-0.353**		-0.0347
		(0.0425)		(0.140)		(0.0497)
Controls						
HHI	0.729***	-0.00466	1.096***	1.060***	0.597*	-0.260**
	(0.218)	(0.116)	(0.178)	(0.249)	(0.316)	(0.127)
Market Share	0.00899***	-0.000249	0.0139***	0.00841***	0.00673***	-0.00239***
	(0.00157)	(0.000747)	(0.00152)	(0.00206)	(0.00205)	(0.000792)
GDP per capita	-3.534***	-0.881***	-0.359	-0.169	-3.818***	-1.018***
	(0.460)	(0.208)	(0.908)	(0.471)	(0.440)	(0.240)
Urban population %	0.0382	-0.0769***	0.0972***	-0.0495	0.0458	-0.0611*
	(0.0394)	(0.0195)	(0.0359)	(0.0406)	(0.112)	(0.0342)
Population density	0.665	-2.436***	0.824	0.568	5.449***	-0.943
	(1.255)	(0.674)	(1.225)	(0.891)	(1.940)	(0.748)
3G spectrum holdings	0.00520***	0.00115***	-0.00382***	-0.00194**	0.00812***	0.00183***
	(0.000711)	(0.000375)	(0.000791)	(0.000805)	(0.000769)	(0.000516)
QoS obligation	1.411***	0.0323	0.101	-0.222***	1.956***	0.184*
	(0.0874)	(0.0700)	(0.0653)	(0.0484)	(0.106)	(0.108)
Constant	12.47**	18.48***	-16.81	-9.780	4.200	22.02***
	(6.134)	(3.212)	(10.39)	(6.274)	(15.23)	(4.807)
Country FE	yes	yes	yes	yes	yes	yes
Time FE	yes	yes	yes	yes	yes	yes
Observations	3,082		1,364		2,075	
Under identification p-value[1]	0.000		0.000		0.000	
Weak identification p-value[2]	0.000		0.000		0.000	
Weak identification F-Statistic[3]	25.730		24.92		20.500	
Overidentification p-value[4]	0.000		N/A		0.000	
Endogeneity p-value[5]	0.033		0.000		0.098	

Cluster-robust standard errors in parentheses

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

1. Reports the p-value of the Kleibergen-Paap rk LM statistic. Null hypothesis is that the model is underidentified.
2. Reports the p-value of the Sanderson-Windmeijer statistic. Null hypothesis is that the model is weakly identified.
3. Reports the Kleibergen-Paap Wald rk F-statistic for weak identification.
4. Reports the p-value of the Hansen's J statistic where more than one instrument is used. Joint null hypothesis is that the instruments are valid and not correlated with the error term.
5. Reports the p-value of the endogeneity test (C statistic). Null hypothesis is that the endogenous regressors are in fact exogenous.

A1.2.4 3G latencies

Figure A1.30

OLS REGRESSION RESULTS USING CPR

	3G latencies (ms)					
	All countries		Developing		Developed	
	(1)	(2)	(3)	(4)	(5)	(6)
Spectrum price						
Average effect	0.0809***		0.0807***		2.886	
	(0.0192)		(0.0198)		(43.89)	
Impact in first year		-0.0478**		-0.0620**		-10.18
		(0.0212)		(0.0254)		(42.92)
Impact in second year		0.109**		0.121**		25.01
		(0.0425)		(0.0487)		(44.96)
Impact after two years		0.584***		0.649***		10.52
		(0.114)		(0.117)		(34.89)
Controls						
HHI	-3.726	-3.456	-37.52	-37.13	7.131	6.392
	(40.96)	(40.91)	(62.10)	(62.17)	(38.19)	(38.48)
Market share	-0.213	-0.212	-0.114	-0.112	-0.479*	-0.474*
	(0.188)	(0.188)	(0.255)	(0.256)	(0.276)	(0.276)
GDP per capita	86.02	86.98	237.6	241.1	35.52	35.90
	(93.82)	(93.85)	(184.9)	(184.3)	(45.48)	(44.96)
Urban population %	-7.412	-7.440	4.822	4.855	-1.657	-1.727
	(4.723)	(4.714)	(6.774)	(6.782)	(5.464)	(5.373)
Population density	-304.0	-304.6	-65.15	-62.21	41.95	39.47
	(290.0)	(290.3)	(440.4)	(440.8)	(146.9)	(149.8)
3G spectrum holdings	0.00772	0.00840	0.0252	0.0272	-0.0308	-0.0323
	(0.0749)	(0.0749)	(0.0612)	(0.0613)	(0.106)	(0.106)
QoS obligation	-2.627	-2.587	-16.26*	-16.21*	6.739	6.698
	(7.039)	(7.041)	(8.841)	(8.760)	(5.922)	(5.935)
Constant	1,218	1,211	-1,741	-1,791	-382.4	-363.4
	(2,321)	(2,321)	(3,548)	(3,543)	(1,122)	(1,125)
Country FE	yes	yes	yes	yes	yes	yes
Time FE	yes	yes	yes	yes	yes	yes
Observations	3,568	3,568	1,468	1,468	2,100	2,100
R-squared	0.599	0.600	0.583	0.583	0.597	0.597

Cluster-robust standard errors in parentheses

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

Figure A1.31

ROBUSTNESS CHECKS USING CPR

	3G latencies (ms)				
	(1)	(2)	(3)	(4)	(5)
	All countries				
Average effect	0.0809***	0.0809	0.0531***	0.000367***	0.0463***
Impact in first year	-0.0478**	-0.0478	-0.0769***	-0.000173*	-0.0243***
Impact in second year	0.109**	0.109	0.0310	0.000581**	0.0821***
Impact after two years	0.584***	0.584***	0.601***	0.00247***	0.373***
3G spectrum holdings	0.00772	0.00772	0.144	-0.000211	0.0275
	Developing countries				
Average effect	0.0807***	0.0807	0.0591***	0.000321**	0.0453***
Impact in first year	-0.0620**	-0.0620*	-0.0782***	-0.000207*	-0.0320***
Impact in second year	0.121**	0.121	0.0707	0.000510**	0.0789***
Impact after two years	0.649***	0.649***	0.656***	0.00244***	0.414***
3G spectrum holdings	0.0252	0.0252	-0.162	0.000224	0.0249
	Developed countries				
Average effect	2.886	2.886	-41.84	0.100	-5.469
Impact in first year	-10.18	-10.18	-32.48	0.0671	-12.78
Impact in second year	25.01	25.01	-6.726	0.262	18.56
Impact after two years	10.52	10.52	-23.51	-0.0824	-4.449
3G spectrum holdings	-0.0308	-0.0308	0.0956	-0.000488	-0.000733
Standard error clusters	Country	Operator	Operator	Country	Country
Country or operator FE	Country	Country	Operator	Country	Country
Time FE	Yes	Yes	Yes	Yes	Yes
Log transformation of 4G upload speeds	No	No	No	Yes	No
Current or Future Revenues	Current	Current	Current	Current	Future

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

Figure A1.32

OLS REGRESSION RESULTS USING LOG OF $PPP/MHZ/POP/LICENCE YEAR

3G latencies (ms)

	All countries		Developing		Developed	
	(1)	(2)	(3)	(4)	(5)	(6)
Spectrum price						
Average effect	0.215		3.128		-3.783	
	(2.781)		(7.416)		(2.392)	
Impact in first year		-0.446		-1.217*		-0.246
		(0.345)		(0.690)		(0.255)
Impact in second year		-0.630		-1.078		-0.142
		(0.413)		(0.720)		(0.318)
Impact after two years		-0.145		0.536		-0.356
		(0.436)		(0.840)		(0.405)
Controls						
HHI	-12.83	-7.058	-18.37	-7.096	-19.91	-26.38
	(44.31)	(44.36)	(64.95)	(59.59)	(33.80)	(32.82)
Market share	-0.310*	-0.297	-0.198	-0.146	-0.537**	-0.559**
	(0.184)	(0.182)	(0.282)	(0.249)	(0.255)	(0.253)
GDP per capita	80.88	78.76	234.7	213.9	22.19	38.25
	(98.02)	(92.80)	(185.2)	(176.0)	(39.93)	(39.37)
Urban population %	-8.425*	-7.685	4.621	8.080	-2.227	-2.757
	(4.673)	(4.686)	(6.804)	(6.193)	(5.780)	(5.705)
Population density	-288.4	-282.9	-91.16	-69.14	164.1	149.6
	(282.4)	(282.6)	(439.3)	(417.1)	(140.2)	(139.2)
3G spectrum holdings	-0.0161	-0.0169	0.0305	-0.0243	-0.0336	-0.0600
	(0.0829)	(0.0845)	(0.0701)	(0.0655)	(0.115)	(0.111)
QoS obligation	-2.710	-1.316	-20.66**	-20.42**	18.18**	10.89*
	(8.591)	(7.722)	(8.852)	(9.887)	(7.635)	(6.089)
Constant	1,359	1,240	-1,731	-1,966	-586.5	-580.8
	(2,279)	(2,256)	(3,499)	(3,275)	(1,112)	(1,042)
Country FE	yes	yes	yes	yes	yes	yes
Time FE	yes	yes	yes	yes	yes	yes
Observations	3,716	3,716	1,511	1,511	2,205	2,205
R-squared	0.585	0.586	0.579	0.584	0.572	0.570

Cluster-robust standard errors in parentheses

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

Figure A1.33

INSTRUMENTAL VARIABLE REGRESSION RESULTS USING LOG OF $PPP/MHZ/POP/LICENCE YEAR

3G latencies (ms)

	All countries		Developing		Developed	
	First stage	Second stage	First stage	Second stage	First stage	Second stage
Instruments						
Short-term debt	0.0355***		0.0364***			
	(0.00759)		(0.00729)			
Non-auction assignment	-0.528***				-0.489***	
	(0.0650)				(0.0625)	
Spectrum price in region	0.232				-0.0654	
	(0.163)				(0.169)	
Reserve price in region	-0.0536				0.217*	
	(0.0840)				(0.121)	
Spectrum price						
Average effect		7.919		11.02		-20.41**
		(7.250)		(11.31)		(10.20)
Controls						
HHI	0.729***	14.30	1.096***	-19.91	0.597*	-13.59
	(0.218)	(17.70)	(0.178)	(30.00)	(0.316)	(18.04)
Market Share	0.00899***	-0.270**	0.0139***	-0.322	0.00673***	-0.389***
	(0.00157)	(0.127)	(0.00152)	(0.207)	(0.00205)	(0.147)
GDP per capita	-3.534***	132.4***	-0.359	287.6***	-3.818***	-47.81
	(0.460)	(34.65)	(0.908)	(60.19)	(0.440)	(48.75)
Urban population %	0.0382	-4.319**	0.0972***	0.229	0.0458	-2.304
	(0.0394)	(2.079)	(0.0359)	(3.745)	(0.112)	(4.931)
Population density	0.665	-197.9**	0.824	-227.8	5.449***	223.4**
	(1.255)	(77.01)	(1.225)	(148.5)	(1.940)	(107.8)
3G spectrum holdings	0.00520***	-0.105**	-0.00382***	0.0267	0.00812***	0.0774
	(0.000711)	(0.0532)	(0.000791)	(0.0760)	(0.000769)	(0.0921)
QoS obligation	1.411***	-7.168	0.101	-21.16***	1.956***	52.64**
	(0.0874)	(10.47)	(0.0653)	(7.785)	(0.106)	(20.74)
Constant	12.47**	9.123	-16.81	-678.6	4.200	-232.6
	(6.134)	(380.3)	(10.39)	(904.3)	(15.23)	(666.7)
Country FE	yes	yes	yes	yes	yes	yes
Time FE	yes	yes	yes	yes	yes	yes
Observations	3,082		1,364		2,075	
Under identification p-value[1]	0.000		0.000		0.000	
Weak identification p-value[2]	0.000		0.000		0.000	
Weak identification F-Statistic[3]	25.730		24.92		20.500	
Overidentification p-value[4]	0.000		N/A		0.000	
Endogeneity p-value[5]	0.257		0.580		0.110	

Cluster-robust standard errors in parentheses

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

1. Reports the p-value of the Kleibergen-Paap rk LM statistic. Null hypothesis is that the model is underidentified.
2. Reports the p-value of the Sanderson-Windmeijer statistic. Null hypothesis is that the model is weakly identified.
3. Reports the Kleibergen-Paap Wald rk F-statistic for weak identification.
4. Reports the p-value of the Hansen's J statistic where more than one instrument is used. Joint null hypothesis is that the instruments are valid and not correlated with the error term.
5. Reports the p-value of the endogeneity test (C statistic). Null hypothesis is that the endogenous regressors are in fact exogenous.

A1.3 All networks

A1.3.1 Download speeds

Figure A1.34

OLS REGRESSION RESULTS USING CPR

All download speeds (Mbps)

	All countries		Developing		Developed	
	(1)	(2)	(3)	(4)	(5)	(6)
Spectrum price						
Average effect	-0.0137***		-0.0111**		-17.16	
	(0.00395)		(0.00534)		(12.22)	
Impact in first year		0.0131		0.0100		-9.905
		(0.0133)		(0.0119)		(9.557)
Impact in second year		-0.0288***		-0.0227**		-19.96
		(0.00628)		(0.00870)		(12.31)
Impact after two years		-0.115		-0.0898		-14.52
		(0.0726)		(0.0712)		(12.54)
Controls						
HHI	0.264	0.214	6.292*	6.250*	-7.465	-7.447
	(5.390)	(5.351)	(3.132)	(3.082)	(6.762)	(6.866)
Market share	0.0522	0.0520	0.0417	0.0416	0.0475	0.0490
	(0.0355)	(0.0354)	(0.0451)	(0.0449)	(0.0529)	(0.0522)
GDP per capita	2.297	2.084	19.94**	19.44**	-3.790	-2.769
	(8.597)	(8.598)	(8.643)	(8.773)	(7.683)	(7.521)
Urban population %	-2.001**	-1.997**	-2.390**	-2.395**	1.623	1.710
	(0.963)	(0.959)	(1.058)	(1.055)	(2.307)	(2.298)
Population density	-63.21***	-63.14***	-71.46**	-71.92**	57.37	59.53
	(23.13)	(23.11)	(34.03)	(33.93)	(42.95)	(43.04)
3G spectrum holdings	0.00443	0.00429	-0.0174*	-0.0176*	0.00736	0.00765
	(0.0183)	(0.0183)	(0.00932)	(0.00943)	(0.0234)	(0.0238)
4G spectrum holdings	0.0680***	0.0679***	0.0902**	0.0901**	0.0601***	0.0614***
	(0.0123)	(0.0123)	(0.0343)	(0.0343)	(0.0126)	(0.0130)
QoS obligation	0.0464	0.0393	0.188	0.178	0.897	0.747
	(1.369)	(1.372)	(1.888)	(1.899)	(1.809)	(1.765)
Constant	416.7***	418.6***	218.9	226.2	-289.3	-317.7
	(131.2)	(131.0)	(182.1)	(183.3)	(296.7)	(297.7)
Country FE	yes	yes	yes	yes	yes	yes
Time FE	yes	yes	yes	yes	yes	yes
Observations	3,577	3,577	1,473	1,473	2,104	2,104
R-squared	0.766	0.766	0.738	0.738	0.774	0.774

Cluster-robust standard errors in parentheses

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

Figure A1.35

ROBUSTNESS CHECKS USING CPR

All download speeds (Mbps)

	(1)	(2)	(3)	(4)	(5)
	All countries				
Average effect	-0.0137***	-0.0137***	-0.00829***	-0.00327***	-0.00667***
Impact in first year	0.0131	0.0131	0.00753	-0.000331	0.00380
Impact in second year	-0.0288***	-0.0288***	-0.0289***	-0.00866***	-0.0196***
Impact after two years	-0.115	-0.115*	-0.0843**	-0.0103*	-0.0530**
	Developing countries				
Average effect	-0.0111**	-0.0111**	-0.00473***	-0.00324***	-0.00489**
Impact in first year	0.0100	0.0100	0.00622	-0.000321	0.00296
Impact in second year	-0.0227**	-0.0227***	-0.0156**	-0.00859***	-0.0138**
Impact after two years	-0.0898	-0.0898	-0.0571*	-0.0102	-0.0396
	Developed countries				
Average effect	-17.16	-17.16*	-6.967	-0.763	-10.88
Impact in first year	-9.905	-9.905	-2.002	-1.280**	-8.857
Impact in second year	-19.96	-19.96*	-7.649	-0.397	-13.10
Impact after two years	-14.52	-14.52	-0.00259	0.242	-7.624
Standard error clusters	Country	Operator	Operator	Country	Country
Country or operator FE	Country	Country	Operator	Country	Country
Time FE	Yes	Yes	Yes	Yes	Yes
Logit transformation of 4G coverage	No	No	No	Yes	No
Current or Future Revenues	Current	Current	Current	Current	Future

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

Figure A1.36

OLS REGRESSION RESULTS USING LOG OF $PPP/MHZ/POP/LICENCE YEAR

All download speeds (Mbps)

	All countries		Developing		Developed	
	(1)	(2)	(3)	(4)	(5)	(6)
Spectrum price						
Average effect	0.642		0.793		0.362	
	(0.398)		(0.996)		(0.328)	
Impact in first year		0.0406		0.101		-0.0603
		(0.0752)		(0.130)		(0.0643)
Impact in second year		0.0365		0.168		-0.0925
		(0.0766)		(0.147)		(0.0552)
Impact after two years		-0.0145		0.0799		-0.112*
		(0.0585)		(0.102)		(0.0581)
Controls						
HHI	-2.003	-1.596	4.004	3.520*	-8.515	-7.334
	(5.298)	(5.234)	(2.359)	(1.942)	(6.794)	(6.914)
Market share	0.0461	0.0510*	0.0398	0.0468	0.0419	0.0449
	(0.0312)	(0.0299)	(0.0474)	(0.0409)	(0.0362)	(0.0361)
GDP per capita	2.920	0.595	20.24**	19.37**	-0.328	-1.541
	(8.094)	(8.640)	(7.999)	(7.656)	(7.049)	(7.127)
Urban population %	-2.186**	-2.195**	-2.806***	-2.837***	2.262	2.400
	(0.929)	(0.939)	(0.875)	(0.864)	(2.346)	(2.410)
Population density	-61.51***	-63.25***	-65.70*	-68.07**	52.24	56.71
	(22.33)	(22.51)	(32.28)	(31.28)	(41.41)	(41.33)
3G spectrum holdings	0.000238	0.00381	-0.0152	-0.0157	0.00155	0.00464
	(0.0142)	(0.0157)	(0.0117)	(0.0101)	(0.0183)	(0.0188)
4G spectrum holdings	0.0663***	0.0665***	0.0954**	0.0919**	0.0595***	0.0610***
	(0.0121)	(0.0129)	(0.0348)	(0.0361)	(0.0123)	(0.0122)
QoS obligation	-0.646	0.159	0.569	0.864	-0.118	0.761
	(1.427)	(1.238)	(1.775)	(1.652)	(1.926)	(1.603)
Constant	439.2***	465.5***	239.3	263.8*	-343.3	-377.4
	(127.7)	(131.7)	(165.3)	(149.4)	(290.4)	(296.4)
Country FE	yes	yes	yes	yes	yes	yes
Time FE	yes	yes	yes	yes	yes	yes
Observations	3,742	3,742	1,524	1,524	2,218	2,218
R-squared	0.762	0.761	0.735	0.736	0.770	0.770

Cluster-robust standard errors in parentheses

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

Figure A1.37

INSTRUMENTAL VARIABLE REGRESSION RESULTS USING LOG OF $PPP/MHZ/POP/LICENCE YEAR

All download speeds (Mbps)

	All countries		Developing		Developed	
	First stage	Second stage	First stage	Second stage	First stage	Second stage
Instruments						
Short-term debt	0.0345***		0.0334***			
	(0.00761)		(0.00714)			
Non-auction assignment	-0.496***				-0.491***	
	(0.0632)				(0.0626)	
Spectrum price in region	0.240				-0.0739	
	(0.162)				(0.169)	
Reserve price in region	-0.0275				0.225*	
	(0.0841)				(0.121)	
Spectrum price						
Average effect		-6.699***		-9.151***		-4.797***
		(1.220)		(3.174)		(1.357)
Controls						
HHI	0.729***	0.730	1.018***	14.06***	0.567*	-8.764***
	(0.215)	(2.731)	(0.178)	(4.493)	(0.316)	(3.095)
Market Share	0.00725***	0.0945***	0.0121***	0.164***	0.00736***	0.0790***
	(0.00156)	(0.0189)	(0.00144)	(0.0422)	(0.00215)	(0.0216)
GDP per capita	-3.359***	-19.81***	-0.386	19.34*	-3.862***	-21.49***
	(0.459)	(6.439)	(0.907)	(10.20)	(0.435)	(6.850)
Urban population %	0.0429	-1.514***	0.0992***	-1.985***	0.0412	2.416***
	(0.0391)	(0.472)	(0.0363)	(0.747)	(0.113)	(0.879)
Population density	1.142	-15.51	1.137	-50.24***	5.360***	108.8***
	(1.260)	(16.71)	(1.255)	(17.11)	(1.967)	(22.18)
3G spectrum holdings	0.00522***	0.0324***	-0.00402***	-0.0585***	0.00846***	0.0404***
	(0.000701)	(0.0103)	(0.000811)	(0.0167)	(0.000758)	(0.0139)
4G spectrum holdings	0.00156***	0.0797***	0.00189**	0.118***	-0.000211	0.0609***
	(0.000393)	(0.00563)	(0.000797)	(0.0137)	(0.000457)	(0.00502)
QoS obligation	1.383***	10.05***	0.166**	1.634	1.949***	10.63***
	(0.0877)	(2.082)	(0.0656)	(1.170)	(0.108)	(3.053)
Constant	9.436	186.8**	-17.12	-69.34	5.570	-365.8***
	(6.153)	(81.46)	(10.41)	(133.7)	(15.48)	(140.9)
Country FE	yes	yes	yes	yes	yes	yes
Time FE	yes	yes	yes	yes	yes	yes
Observations	3,103		1,375		2,088	
Under identification p-value[1]	0.000		0.000		0.000	
Weak identification p-value[2]	0.000		0.000		0.000	
Weak identification F-Statistic[3]	24.480		21.92		20.680	
Overidentification p-value[4]	0.013		N/A		0.002	
Endogeneity p-value[5]	0.000		0.000		0.000	

Cluster-robust standard errors in parentheses

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

1. Reports the p-value of the Kleibergen-Paap rk LM statistic. Null hypothesis is that the model is underidentified.
2. Reports the p-value of the Sanderson-Windmeijer statistic. Null hypothesis is that the model is weakly identified.
3. Reports the Kleibergen-Paap Wald rk F-statistic for weak identification.
4. Reports the p-value of the Hansen's J statistic where more than one instrument is used. Joint null hypothesis is that the instruments are valid and not correlated with the error term.
5. Reports the p-value of the endogeneity test (C statistic). Null hypothesis is that the endogenous regressors are in fact exogenous.

A1.3.2 Upload speeds

Figure A1.38

OLS REGRESSION RESULTS USING CPR

All upload speeds (Mbps)

	All countries		Developing		Developed	
	(1)	(2)	(3)	(4)	(5)	(6)
Spectrum price						
Average effect	-0.00419*		-0.00340		-3.252	
	(0.00224)		(0.00296)		(4.256)	
Impact in first year		0.00743		0.00653		-3.688
		(0.00729)		(0.00720)		(4.264)
Impact in second year		-0.00641*		-0.00430		-3.440
		(0.00354)		(0.00447)		(4.340)
Impact after two years		-0.0518		-0.0443		0.586
		(0.0407)		(0.0429)		(3.817)
Controls						
HHI	-1.500	-1.527	0.416	0.384	-4.654	-4.670
	(2.402)	(2.381)	(2.291)	(2.257)	(3.377)	(3.442)
Market share	-0.00002	-0.000129	-0.00225	-0.00238	0.00491	0.00613
	(0.0197)	(0.0196)	(0.0254)	(0.0253)	(0.0301)	(0.0295)
GDP per capita	5.876	5.784	10.59*	10.35	4.896	5.062
	(3.653)	(3.647)	(6.014)	(6.084)	(4.020)	(4.038)
Urban population %	-0.512	-0.509	-0.586	-0.587	0.0293	0.0232
	(0.348)	(0.346)	(0.471)	(0.470)	(0.775)	(0.767)
Population density	-6.533	-6.494	-10.07	-10.28	25.12	24.64
	(13.60)	(13.57)	(20.13)	(20.10)	(15.86)	(15.78)
3G spectrum holdings	-0.000412	-0.000470	-0.0117*	-0.0118*	0.00351	0.00306
	(0.00618)	(0.00619)	(0.00646)	(0.00643)	(0.00806)	(0.00809)
4G spectrum holdings	0.0242***	0.0242***	0.0331	0.0331	0.0188***	0.0191***
	(0.00634)	(0.00633)	(0.0224)	(0.0224)	(0.00497)	(0.00502)
QoS obligation	-0.0622	-0.0649	-0.611	-0.614	0.569	0.544
	(0.726)	(0.727)	(0.702)	(0.707)	(0.991)	(0.980)
Constant	25.20	25.98	-18.28	-14.79	-130.8	-129.7
	(68.25)	(68.07)	(93.63)	(94.49)	(120.4)	(119.9)
Country FE	yes	yes	yes	yes	yes	yes
Time FE	yes	yes	yes	yes	yes	yes
Observations	3,577	3,577	1,473	1,473	2,104	2,104
R-squared	0.737	0.737	0.695	0.696	0.756	0.756

Cluster-robust standard errors in parentheses

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

Figure A1.39

ROBUSTNESS CHECKS USING CPR

All upload speeds (Mbps)

	(1)	(2)	(3)	(4)	(5)
	All countries				
Average effect	-0.00419*	-0.00419**	-0.00314***	-0.00315***	-0.00199**
Impact in first year	0.00743	0.00743	0.00360	0.000315	0.00212
Impact in second year	-0.00641*	-0.00641*	-0.00818*	-0.00709***	-0.00496***
Impact after two years	-0.0518	-0.0518	-0.0341*	-0.0137*	-0.0216
	Developing countries				
Average effect	-0.00340	-0.00340	-0.00169*	-0.00317***	-0.00139
Impact in first year	0.00653	0.00653	0.00293	0.000328	0.00192
Impact in second year	-0.00430	-0.00430	-0.00253	-0.00718***	-0.00292
Impact after two years	-0.0443	-0.0443	-0.0222	-0.0139	-0.0175
	Developed countries				
Average effect	-3.252	-3.252	-0.540	-0.659	-1.994
Impact in first year	-3.688	-3.688	-1.681	-1.483**	-4.321
Impact in second year	-3.440	-3.440	-0.306	-0.0459	-2.578
Impact after two years	0.586	0.586	4.193	0.661	1.383
Standard error clusters	Country	Operator	Operator	Country	Country
Country or operator FE	Country	Country	Operator	Country	Country
Time FE	Yes	Yes	Yes	Yes	Yes
Log transformation of 4G upload speeds	No	No	No	Yes	No
Current or Future Revenues	Current	Current	Current	Current	Future

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

Figure A1.40

OLS REGRESSION RESULTS USING LOG OF $PPP/MHZ/POP/LICENCE YEAR

All upload speeds (Mbps)

	All countries		Developing		Developed	
	(1)	(2)	(3)	(4)	(5)	(6)
Spectrum price						
Average effect	0.324*		0.630		0.0877	
	(0.182)		(0.553)		(0.157)	
Impact in first year		0.0367		0.0780		-0.0133
		(0.0365)		(0.0726)		(0.0357)
Impact in second year		0.0695*		0.123		0.00717
		(0.0396)		(0.0832)		(0.0341)
Impact after two years		0.0355		0.0464		-0.000970
		(0.0322)		(0.0651)		(0.0314)
Controls						
HHI	-3.470	-3.556	-1.095	-1.389	-6.624*	-6.444*
	(2.421)	(2.412)	(2.168)	(2.039)	(3.286)	(3.368)
Market share	-0.00431	-0.00214	-0.00624	-0.000335	-0.00510	-0.00430
	(0.0174)	(0.0168)	(0.0251)	(0.0214)	(0.0228)	(0.0228)
GDP per capita	6.639**	5.288	9.670*	9.191	5.921*	5.585
	(3.294)	(3.372)	(5.654)	(5.427)	(3.458)	(3.551)
Urban population %	-0.731**	-0.765**	-0.846**	-0.885**	-0.0535	-0.0145
	(0.330)	(0.332)	(0.389)	(0.393)	(0.718)	(0.730)
Population density	-2.824	-4.412	-8.174	-10.08	29.59*	30.59*
	(13.12)	(13.37)	(19.01)	(19.39)	(15.81)	(15.82)
3G spectrum holdings	-0.000682	0.00100	-0.0117	-0.0120	0.00503	0.00561
	(0.00582)	(0.00644)	(0.00902)	(0.00808)	(0.00747)	(0.00782)
4G spectrum holdings	0.0239***	0.0231***	0.0376	0.0349	0.0182***	0.0182***
	(0.00649)	(0.00679)	(0.0227)	(0.0231)	(0.00488)	(0.00493)
QoS obligation	-0.0208	0.385	-0.0306	0.177	0.764	0.986
	(0.688)	(0.713)	(0.838)	(0.821)	(0.995)	(0.945)
Constant	33.71	57.79	12.83	30.16	-141.4	-147.8
	(65.24)	(68.93)	(90.37)	(89.83)	(120.5)	(122.9)
Country FE	yes	yes	yes	yes	yes	yes
Time FE	yes	yes	yes	yes	yes	yes
Observations	3,742	3,742	1,524	1,524	2,218	2,218
R-squared	0.725	0.725	0.684	0.687	0.747	0.747

Cluster-robust standard errors in parentheses

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

Figure A1.41

INSTRUMENTAL VARIABLE REGRESSION RESULTS USING LOG OF $PPP/MHZ/POP/LICENCE YEAR

All upload speeds (Mbps)

	All countries		Developing		Developed	
	First stage	Second stage	First stage	Second stage	First stage	Second stage
Instruments						
Short-term debt	0.0345***		0.0334***			
	(0.00761)		(0.00714)			
Non-auction assignment	-0.496***				-0.491***	
	(0.0632)				(0.0626)	
Spectrum price in region	0.240				-0.0739	
	(0.162)				(0.169)	
Reserve price in region	-0.0275				0.225*	
	(0.0841)				(0.121)	
Spectrum price						
Average effect		-3.698***		-3.958**		-3.172***
		(0.589)		(1.553)		(0.705)
Controls						
HHI	0.729***	-1.467	1.018***	2.647	0.567*	-3.931***
	(0.215)	(1.331)	(0.178)	(2.266)	(0.316)	(1.397)
Market Share	0.00725***	0.0162*	0.0121***	0.0471**	0.00736***	0.0230**
	(0.00156)	(0.00961)	(0.00144)	(0.0209)	(0.00215)	(0.0112)
GDP per capita	-3.359***	-5.039	-0.386	8.922*	-3.862***	-7.178**
	(0.459)	(3.112)	(0.907)	(4.763)	(0.435)	(3.402)
Urban population %	0.0429	-0.257	0.0992***	-0.420	0.0412	0.0776
	(0.0391)	(0.249)	(0.0363)	(0.371)	(0.113)	(0.421)
Population density	1.142	18.70**	1.137	3.477	5.360***	47.61***
	(1.260)	(7.432)	(1.255)	(8.021)	(1.967)	(10.22)
3G spectrum holdings	0.00522***	0.0170***	-0.00402***	-0.0295***	0.00846***	0.0283***
	(0.000701)	(0.00508)	(0.000811)	(0.00681)	(0.000758)	(0.00705)
4G spectrum holdings	0.00156***	0.0309***	0.00189**	0.0470***	-0.000211	0.0187***
	(0.000393)	(0.00259)	(0.000797)	(0.00719)	(0.000457)	(0.00211)
QoS obligation	1.383***	5.984***	0.166**	0.501	1.949***	7.485***
	(0.0877)	(0.998)	(0.0656)	(0.527)	(0.108)	(1.582)
Constant	9.436	-44.90	-17.12	-115.1*	5.570	-133.2**
	(6.153)	(37.98)	(10.41)	(64.33)	(15.48)	(67.48)
Country FE	yes	yes	yes	yes	yes	yes
Time FE	yes	yes	yes	yes	yes	yes
Observations	3,103		1,375		2,088	
Under identification p-value[1]	0.000		0.000		0.000	
Weak identification p-value[2]	0.000		0.000		0.000	
Weak identification F-Statistic[3]	24.480		21.92		20.680	
Overidentification p-value[4]	0.038		N/A		0.001	
Endogeneity p-value[5]	0.000		0.000		0.000	

Cluster-robust standard errors in parentheses

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

1. Reports the p-value of the Kleibergen-Paap rk LM statistic. Null hypothesis is that the model is underidentified.
2. Reports the p-value of the Sanderson-Windmeijer statistic. Null hypothesis is that the model is weakly identified.
3. Reports the Kleibergen-Paap Wald rk F-statistic for weak identification.
4. Reports the p-value of the Hansen's J statistic where more than one instrument is used. Joint null hypothesis is that the instruments are valid and not correlated with the error term.
5. Reports the p-value of the endogeneity test (C statistic). Null hypothesis is that the endogenous regressors are in fact exogenous.

A1.3.3 Latencies

Figure A1.42

OLS REGRESSION RESULTS USING CPR

All latencies (ms)

	All countries		Developing		Developed	
	(1)	(2)	(3)	(4)	(5)	(6)
Spectrum price						
Average effect	0.126***		0.116***		17.09	
	(0.0289)		(0.0328)		(50.59)	
Impact in first year		-0.0990		-0.125*		51.80
		(0.0598)		(0.0685)		(51.00)
Impact in second year		0.203**		0.219**		6.748
		(0.0917)		(0.0890)		(65.97)
Impact after two years		1.008***		1.081***		-32.04
		(0.252)		(0.297)		(44.95)
Controls						
HHI	39.63	40.10	-18.02	-17.44	31.61	31.69
	(56.45)	(56.14)	(53.39)	(52.70)	(42.58)	(43.84)
Market share	0.158	0.159	0.357	0.358	-0.292	-0.303
	(0.301)	(0.301)	(0.426)	(0.426)	(0.322)	(0.328)
GDP per capita	-22.95	-21.15	45.78	51.90	-61.58	-61.71
	(103.5)	(103.5)	(173.1)	(173.3)	(58.12)	(56.68)
Urban population %	-13.61	-13.66	14.79	14.85	-0.871	-0.587
	(9.828)	(9.809)	(15.47)	(15.45)	(10.03)	(9.862)
Population density	-1,101**	-1,102**	-1,110	-1,104	197.0	208.9
	(474.5)	(475.1)	(679.5)	(680.4)	(196.8)	(198.1)
3G spectrum holdings	-0.104	-0.103	-0.367	-0.363	-0.0260	-0.0184
	(0.122)	(0.122)	(0.236)	(0.238)	(0.134)	(0.134)
4G spectrum holdings	-0.194***	-0.193***	-0.297	-0.296	-0.176***	-0.177***
	(0.0620)	(0.0619)	(0.177)	(0.176)	(0.0530)	(0.0541)
QoS obligation	-5.133	-5.077	-6.210	-6.095	5.893	5.753
	(10.54)	(10.55)	(18.87)	(18.96)	(9.262)	(9.508)
Constant	6,049**	6,034**	3,713	3,625	-356.7	-435.2
	(2,604)	(2,604)	(2,887)	(2,885)	(1,789)	(1,773)
Country FE	yes	yes	yes	yes	yes	yes
Time FE	yes	yes	yes	yes	yes	yes
Observations	3,577	3,577	1,473	1,473	2,104	2,104
R-squared	0.641	0.641	0.614	0.615	0.728	0.729

Cluster-robust standard errors in parentheses

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

Figure A1.43

ROBUSTNESS CHECKS USING CPR

All latencies (ms)

	(1)	(2)	(3)	(4)	(5)
	All countries				
Average effect	0.126***	0.126	0.102***	0.000590***	0.0714***
Impact in first year	-0.0990	-0.0990	-0.121*	-0.000683	-0.0307**
Impact in second year	0.203**	0.203	0.199**	0.000971**	0.161***
Impact after two years	1.008***	1.008***	1.094***	0.00576***	0.532***
	Developing countries				
Average effect	0.116***	0.116	0.113***	0.000472**	0.0646***
Impact in first year	-0.125*	-0.125	-0.121*	-0.000706	-0.0463**
Impact in second year	0.219**	0.219	0.333***	0.000819*	0.154***
Impact after two years	1.081***	1.081***	1.220***	0.00535**	0.587***
	Developed countries				
Average effect	17.09	17.09	-24.03	0.0799	31.19
Impact in first year	51.80	51.80	24.63	0.415	61.03**
Impact in second year	6.748	6.748	-34.23	0.149	42.77
Impact after two years	-32.04	-32.04	-68.45	-0.366	-7.013
Standard error clusters	Country	Operator	Operator	Country	Country
Country or operator FE	Country	Country	Operator	Country	Country
Time FE	Yes	Yes	Yes	Yes	Yes
Log transformation of 4G upload speeds	No	No	No	Yes	No
Current or Future Revenues	Current	Current	Current	Current	Future

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

Figure A1.44

OLS REGRESSION RESULTS USING LOG OF $PPP/MHZ/POP/LICENCE YEAR

All latencies (ms)

	All countries		Developing		Developed	
	(1)	(2)	(3)	(4)	(5)	(6)
Spectrum price						
Average effect	2.278		-2.336		-1.479	
	(2.486)		(6.632)		(2.931)	
Impact in first year		0.152		-0.397		0.267
		(0.622)		(1.196)		(0.501)
Impact in second year		-1.747***		-3.320***		-0.0139
		(0.595)		(0.918)		(0.559)
Impact after two years		-0.908*		-0.729		-0.287
		(0.502)		(0.992)		(0.485)
Controls						
HHI	27.60	38.96	-11.15	6.733	39.09	33.17
	(53.49)	(53.50)	(51.17)	(50.06)	(40.54)	(40.99)
Market share	0.102	0.115	0.310	0.292	-0.206	-0.214
	(0.269)	(0.263)	(0.429)	(0.413)	(0.244)	(0.242)
GDP per capita	-7.648	-10.40	61.21	65.97	-69.54	-64.38
	(104.2)	(102.3)	(177.4)	(163.4)	(60.54)	(57.21)
Urban population %	-13.30	-12.49	16.42	16.64	-1.380	-2.326
	(8.792)	(8.742)	(14.93)	(14.15)	(10.00)	(10.71)
Population density	-1,060**	-1,050**	-1,105	-1,097	238.8	221.7
	(455.4)	(456.7)	(662.6)	(665.4)	(189.1)	(194.3)
3G spectrum holdings	-0.0976	-0.0817	-0.391	-0.405*	-0.00457	-0.0126
	(0.107)	(0.103)	(0.240)	(0.211)	(0.113)	(0.109)
4G spectrum holdings	-0.200***	-0.161***	-0.313*	-0.211	-0.181***	-0.187***
	(0.0607)	(0.0590)	(0.178)	(0.155)	(0.0486)	(0.0526)
QoS obligation	-13.19	-11.24	-18.85	-22.60	10.08	5.965
	(13.06)	(12.80)	(26.06)	(26.31)	(8.025)	(7.530)
Constant	5,827**	5,618**	3,396	3,115	-512.1	-353.1
	(2,541)	(2,543)	(2,826)	(2,702)	(1,799)	(1,856)
Country FE	yes	yes	yes	yes	yes	yes
Time FE	yes	yes	yes	yes	yes	yes
Observations	3,742	3,742	1,524	1,524	2,218	2,218
R-squared	0.637	0.641	0.612	0.619	0.726	0.726

Cluster-robust standard errors in parentheses

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

Figure A1.45

INSTRUMENTAL VARIABLE REGRESSION RESULTS USING LOG OF $PPP/MHZ/POP/LICENCE YEAR

All latencies (ms)

	All countries		Developing		Developed	
	First stage	Second stage	First stage	Second stage	First stage	Second stage
Instruments						
Short-term debt	0.0345***		0.0334***			
	(0.00761)		(0.00714)			
Non-auction assignment	-0.496***				-0.491***	
	(0.0632)				(0.0626)	
Spectrum price in region	0.240				-0.0739	
	(0.162)				(0.169)	
Reserve price in region	-0.0275				0.225*	
	(0.0841)				(0.121)	
Spectrum price						
Average effect		27.36***		26.10		-0.0789
		(8.494)		(19.53)		(10.16)
Controls						
HHI	0.729***	15.39	1.018***	-13.20	0.567*	24.72
	(0.215)	(23.58)	(0.178)	(39.87)	(0.316)	(20.98)
Market Share	0.00725***	-0.0940	0.0121***	-0.101	0.00736***	-0.322**
	(0.00156)	(0.136)	(0.00144)	(0.291)	(0.00215)	(0.153)
GDP per capita	-3.359***	87.03**	-0.386	175.9**	-3.862***	-69.85
	(0.459)	(37.67)	(0.907)	(78.15)	(0.435)	(49.32)
Urban population %	0.0429	-10.59***	0.0992***	5.377	0.0412	-1.497
	(0.0391)	(3.528)	(0.0363)	(5.816)	(0.113)	(4.972)
Population density	1.142	-336.8***	1.137	-836.5***	5.360***	243.2**
	(1.260)	(101.1)	(1.255)	(221.0)	(1.967)	(104.6)
3G spectrum holdings	0.00522***	-0.166***	-0.00402***	-0.107	0.00846***	0.00994
	(0.000701)	(0.0599)	(0.000811)	(0.139)	(0.000758)	(0.0929)
4G spectrum holdings	0.00156***	-0.260***	0.00189**	-0.435***	-0.000211	-0.175***
	(0.000393)	(0.0306)	(0.000797)	(0.0858)	(0.000457)	(0.0277)
QoS obligation	1.383***	-31.41**	0.166**	-28.35**	1.949***	8.317
	(0.0877)	(12.91)	(0.0656)	(12.18)	(0.108)	(20.68)
Constant	9.436	1,248**	-17.12	2,568**	5.570	-281.9
	(6.153)	(487.1)	(10.41)	(1,159)	(15.48)	(692.5)
Country FE	yes	yes	yes	yes	yes	yes
Time FE	yes	yes	yes	yes	yes	yes
Observations	3,103		1,375		2,088	
Under identification p-value[1]	0.000		0.000		0.000	
Weak identification p-value[2]	0.000		0.000		0.000	
Weak identification F-Statistic[3]	24.480		21.92		20.680	
Overidentification p-value[4]	0.000		N/A		0.000	
Endogeneity p-value[5]	0.001		0.135		0.826	

Cluster-robust standard errors in parentheses

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

1. Reports the p-value of the Kleibergen-Paap rk LM statistic. Null hypothesis is that the model is underidentified.
2. Reports the p-value of the Sanderson-Windmeijer statistic. Null hypothesis is that the model is weakly identified.
3. Reports the Kleibergen-Paap Wald rk F-statistic for weak identification.
4. Reports the p-value of the Hansen's J statistic where more than one instrument is used. Joint null hypothesis is that the instruments are valid and not correlated with the error term.
5. Reports the p-value of the endogeneity test (C statistic). Null hypothesis is that the endogenous regressors are in fact exogenous.

A1.4 Consumer prices

A1.4.1 ARPU

Figure A1.46

OLS REGRESSION RESULTS USING LOG OF PRICE $/MHZ/POP/LICENCE YEAR

	Log of ARPU ($PPP)					
	All countries		Developing		Developed	
	(1)	(2)	(4)	(5)	(7)	(8)
Spectrum price						
Average effect	0.00146		-0.00220		0.00126	
	(0.0130)		(0.0395)		(0.0145)	
Impact in first year		0.00592		0.0129*		0.000210
		(0.00366)		(0.00713)		(0.00205)
Impact in second year		0.00561		0.0119**		-0.000172
		(0.00337)		(0.00556)		(0.00220)
Impact after two years		0.00501*		0.0108**		-0.000226
		(0.00255)		(0.00404)		(0.00220)
Controls						
HHI	0.465***	0.421**	0.738*	0.642*	0.364***	0.367***
	(0.170)	(0.160)	(0.385)	(0.374)	(0.127)	(0.113)
Market share	0.00426	0.00407	0.00568	0.00520	0.00264	0.00265
	(0.00326)	(0.00310)	(0.00594)	(0.00545)	(0.00177)	(0.00176)
GDP per capita	0.622**	0.620**	1.122***	1.078***	0.355*	0.348**
	(0.240)	(0.243)	(0.356)	(0.378)	(0.180)	(0.169)
Urban population %	-0.0175	-0.0240	-0.0197	-0.0343	-0.0324	-0.0319
	(0.0175)	(0.0167)	(0.0262)	(0.0286)	(0.0217)	(0.0203)
Population density	-1.115***	-1.170***	-0.955	-1.149	-0.799	-0.800
	(0.380)	(0.366)	(0.630)	(0.674)	(0.744)	(0.749)
Constant	-0.769	0.515	-8.684	-5.377	2.805	2.823
	(3.996)	(3.754)	(6.791)	(6.708)	(4.798)	(4.880)
Country FE	yes	yes	yes	yes	yes	yes
Time FE	yes	yes	yes	yes	yes	yes
Observations	3,535	3,535	1,263	1,263	2,272	2,272
R-squared	0.758	0.759	0.633	0.641	0.755	0.755

Cluster-robust standard errors in parentheses

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

Figure A1.47

INSTRUMENTAL VARIABLE REGRESSION RESULTS USING LOG OF $PPP/MHZ/POP/LICENCE YEAR

	Log of ARPU ($PPP)					
	All countries		Developing		Developed	
	First stage	Second stage	First stage	Second stage	First stage	Second stage
Instruments						
Short-term debt	0.00655		0.0458***			
	(0.00770)		(0.00830)			
Non-auction assignment	-0.894***				-1.222***	
	(0.0998)				(0.126)	
Spectrum price in region	0.737***				0.635***	
	(0.196)				(0.205)	
Reserve price in region	0.0358				0.138	
	(0.104)				(0.0991)	
Spectrum price						
Average effect		-0.100***		0.180***		-0.0611***
		(0.0328)		(0.0698)		(0.0174)
Controls						
HHI	1.433***	0.635***	0.0570	0.711**	2.792***	0.546***
	(0.260)	(0.129)	(0.300)	(0.290)	(0.374)	(0.110)
Market Share	0.0161***	0.00277***	0.0176***	0.00272	0.0133***	0.00336***
	(0.00158)	(0.000767)	(0.00168)	(0.00174)	(0.00208)	(0.000542)
GDP per capita	-4.153***	0.115	0.0501	1.196***	-5.719***	-0.0126
	(0.453)	(0.174)	(0.912)	(0.405)	(0.405)	(0.150)
Urban population %	-0.00400	-0.0193	0.152***	-0.0398*	0.542***	-0.00220
	(0.0513)	(0.0139)	(0.0430)	(0.0231)	(0.134)	(0.0149)
Population density	-4.255***	-1.445***	1.149	-0.766	2.615	-0.430
	(1.325)	(0.453)	(1.249)	(0.839)	(1.787)	(0.421)
Constant	45.08***	3.906	-14.51	-6.907	-5.422	0.759
	(8.461)	(2.830)	(10.24)	(6.458)	(15.88)	(2.803)
Country FE	yes	yes	yes	yes	yes	yes
Time FE	yes	yes	yes	yes	yes	yes
Observations	2,933		1,145		2,128	
Under identification p-value[1]	0.000		0.000		0.000	
Weak identification p-value[2]	0.000		0.000		0.000	
Weak identification F-Statistic[3]	25.790		30.45		37.560	
Overidentification p-value[4]	0.143		N/A		0.00	
Endogeneity p-value[5]	0.001		0.005		0.000	

Cluster-robust standard errors in parentheses

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

1. Reports the p-value of the Kleibergen-Paap rk LM statistic. Null hypothesis is that the model is underidentified.
2. Reports the p-value of the Sanderson-Windmeijer statistic. Null hypothesis is that the model is weakly identified.
3. Reports the Kleibergen-Paap Wald rk F-statistic for weak identification.
4. Reports the p-value of the Hansen's J statistic where more than one instrument is used. Joint null hypothesis is that the instruments are valid and not correlated with the error term.
5. Reports the p-value of the endogeneity test (C statistic). Null hypothesis is that the endogenous regressors are in fact exogenous.

The next table presents the results of the Arellano-Bond analysis, which includes a lag of ARPU. Both the ARPU lag and spectrum price are instrumented using the second-lag as well as external instruments (short-term government debt in developing countries and assignment method, spectrum price in regional countries and reserve prices in regional countries for developed countries). Four different specification are presented. The first is a "difference-GMM" estimator where first differences are instrumented using lagged levels. The second is a difference-GMM using a two-step estimator. The third is a "system-GMM" estimator where lagged levels are included in the specification in additional to lagged differences (as lagged levels are sometimes poor instruments for first differences). The fourth is a system-GMM using a two-step estimator.

Figure A1.48

ARELLANO-BOND REGRESSION RESULTS USING LOG OF $PPP/MHZ/POP/LICENCE YEAR

	Log of ARPU ($PPP)					
	All countries				Developing	
	(1)	(2)	(3)	(4)	(5)	(6)
Spectrum price						
Average effect	-0.0677**	-0.0531*	0.00480	0.00477	-0.0415	-0.0455
	(0.0284)	(0.0300)	(0.00328)	(0.00340)	(0.0936)	(0.0950)
Spectrum price outliers						
75th percentile	-0.0305	-0.0260	0.00302*	0.00292	-0.00616	-0.00306
	(0.0235)	(0.0174)	(0.00182)	(0.00212)	(0.0273)	(0.0238)
Inner fence	-0.0379	-0.0230	0.00621**	0.00671**	0.0193	0.0149
	(0.0295)	(0.0272)	(0.00279)	(0.00261)	(0.0285)	(0.0180)
Outer fence	-0.0761**	-0.0723	0.00895	0.00901	0.0411	0.0295
	(0.0345)	(0.0482)	(0.00550)	(0.00594)	(0.0317)	(0.0266)
Controls						
$ARPU_{t-1}$	0.199**	0.158*	0.951***	0.948***	0.0264	0.0282
	(0.0780)	(0.0895)	(0.0333)	(0.0352)	(0.178)	(0.168)
HHI	0.300***	0.277**	-0.000601	0.00769	0.423*	0.338
	(0.113)	(0.125)	(0.0267)	(0.0296)	(0.250)	(0.251)
Market share	-0.0113***	-0.0105***	0.000393	0.000299	-0.0180**	-0.0159**
	(0.00275)	(0.00357)	(0.000256)	(0.000270)	(0.00708)	(0.00763)
GDP per capita	-0.147	-0.149	0.0306**	0.0310**	-0.272	-0.311
	(0.0970)	(0.109)	(0.0143)	(0.0152)	(0.278)	(0.300)
Urban population %	-0.0254	-0.0416	-0.000275	-0.000293*	-0.0476*	-0.0471
	(0.0202)	(0.0282)	(0.000171)	(0.000176)	(0.0280)	(0.0329)
Population density	-1.289**	-1.231**	0.000214	1.80e-05	-2.921***	-2.464**
	(0.618)	(0.597)	(0.00196)	(0.00182)	(1.063)	(1.115)
Difference or system GMM	Difference	Difference	System	System	Difference	Difference
Estimator	One-step	Two-step	One-step	Two-step	One-step	Two-step
Observations	2,663	2,663	2,830	2,830	854	854
Number of groups	167	167	167	167	68	68
Number of instruments	57	57	108	108	56	56
AR(1) p-value[1]	0.001	0.039	0.000	0.000	0.610	0.769
AR(2) p-value[2]	0.031	0.034	0.026	0.025	0.047	0.060
Overidentification p-value[3]	0.000	0.000	0.002	0.002	0.202	0.202

Cluster-robust standard errors in parentheses

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

1. Reports the p-value of the Arellano-Bond test for AR(1) in first differences. Null hypothesis is that there is no autocorrelation.
2. Reports the p-value of the Arellano-Bond test for AR(2) in first differences. Null hypothesis is that there is no autocorrelation.
3. Reports the p-value of the Hansen's J statistic. Null hypothesis is that the instruments as a group are exogenous.

The results suggest that excessive spectrum prices in developing countries drove higher ARPU when using the system GMM. The diagnostics for all models show that the autocorrelation test for second differences (AR2 p-value) is not rejected at the 1% level (though it is rejected at the 5% level). The Hansen test for whether instruments are exogenous shows that they are valid in both the difference and system GMM models. The results therefore suggest that there is some evidence that excessive spectrum prices in developing countries drove higher ARPU, though it is not definitive. The results for developed countries suggest there is some evidence that higher spectrum prices drove higher ARPU, based on the results of the system GMM models, which according to the Hansen test appear to be based on valid instruments (unlike the difference GMM). However, for both developed and developing countries the system GMM estimator has more instruments than groups, which is not desirable in a DPD framework.

Figure A1.48 (cont.)

ARELLANO-BOND REGRESSION RESULTS USING LOG OF $PPP/MHZ/POP/LICENCE YEAR (cont.)

	Log of ARPU ($PPP)					
	Developing		Developed			
	(7)	(8)	(9)	(10)	(11)	(12)
Spectrum price						
Average effect	0.00009	0.00129	-0.0235**	-0.0235*	0.00459**	0.00462*
	(0.00969)	(0.0102)	(0.0113)	(0.0125)	(0.00229)	(0.00252)
Spectrum price outliers						
75th percentile	0.00367	0.00377	-0.0225**	-0.0209**	0.00271	0.00265
	(0.00264)	(0.00269)	(0.00916)	(0.00984)	(0.00185)	(0.00191)
Inner fence	0.0133**	0.0135**	-0.0137	-0.0115	0.00314	0.00314
	(0.00606)	(0.00618)	(0.0152)	(0.0161)	(0.00307)	(0.00308)
Outer fence	0.0187**	0.0190**	-0.0212	-0.0176	0.00330	0.00328
	(0.00869)	(0.00898)	(0.0225)	(0.0237)	(0.00359)	(0.00360)
Controls						
$ARPU_{t-1}$	0.890***	0.893***	0.586***	0.585***	0.962***	0.961***
	(0.0519)	(0.0524)	(0.0617)	(0.0678)	(0.0114)	(0.0126)
HHI	0.0298	0.0279	0.254***	0.272**	0.0174	0.0175
	(0.0460)	(0.0468)	(0.0781)	(0.109)	(0.0123)	(0.0133)
Market share	0.000700	0.000664	-0.00670***	-0.00671***	0.00004	0.00003
	(0.000517)	(0.000545)	(0.00143)	(0.00199)	(0.000154)	(0.000169)
GDP per capita	0.0480**	0.0469**	-0.0305	-0.0378	0.0143	0.0140
	(0.0200)	(0.0209)	(0.0771)	(0.0850)	(0.00884)	(0.00976)
Urban population %	-0.000955	-0.000855	-0.0398*	-0.0348	0.000127	0.000118
	(0.000648)	(0.000780)	(0.0206)	(0.0243)	(0.000141)	(0.000145)
Population density	-0.00498	-0.00351	0.134	0.114	-0.000846	-0.000725
	(0.0148)	(0.0158)	(0.488)	(0.573)	(0.00152)	(0.00169)
Difference or system GMM	System	System	Difference	Difference	System	System
Estimator	One-step	Two-step	One-step	Two-step	One-step	Two-step
Observations	922	922	1,935	1,935	2,038	2,038
Number of groups	68	68	103	103	103	103
Number of instruments	97	97	65	65	119	119
AR(1) p-value[1]	0.000	0.000	0.000	0.000	0.000	0.000
AR(2) p-value[2]	0.018	0.017	0.588	0.586	0.572	0.571
Overidentification p-value[3]	0.969	0.969	0.004	0.004	0.753	0.753

A1.4.2 ITU baskets

Figure A1.49

OLS REGRESSION RESULTS USING CPR

Log of basket price ($PPP)

	All countries		Developing		Developed	
	Voice Basket	MBB Basket	Voice Basket	MBB Basket	Voice Basket	MBB Basket
Spectrum price						
Average effect	0.00146***	0.00505***	0.00201**	0.00488***	-1.275	2.068
	(0.000434)	(0.000560)	(0.000761)	(0.000692)	(2.188)	(1.764)
Controls						
HHI	-9.63e-05**	0.000159**	-0.000203***	0.000136	-1.41e-05	0.000199**
	(4.36e-05)	(7.17e-05)	(4.58e-05)	(0.000116)	(3.79e-05)	(8.47e-05)
GDP per capita	-4.79e-06	-1.52e-05	1.28e-05	3.71e-05	-1.16e-05*	-1.58e-05
	(9.04e-06)	(1.24e-05)	(6.38e-05)	(3.78e-05)	(6.58e-06)	(1.10e-05)
Urban population %	-0.0131	0.0885*	-0.00424	0.113*	-0.0296	0.00681
	(0.0679)	(0.0523)	(0.0653)	(0.0582)	(0.0929)	(0.136)
Population density	0.00104**	-0.000991	0.0479***	0.00683	0.000859*	-0.00135
	(0.000501)	(0.00182)	(0.0164)	(0.00867)	(0.000493)	(0.00192)
Constant	3.832	-3.380	-0.483	-5.680	5.184	2.808
	(4.954)	(3.919)	(3.616)	(4.259)	(7.442)	(10.89)
Country FE	yes	yes	yes	yes	yes	yes
Time FE	yes	yes	yes	yes	yes	yes
Observations	334	302	139	125	195	177
R-squared	0.786	0.700	0.905	0.799	0.710	0.674

Cluster-robust standard errors in parentheses

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

Figure A1.50

OLS REGRESSION RESULTS USING COST AS A PERCENTAGE OF FUTURE REVENUE

Log of basket price ($PPP)

	All countries		Developing		Developed	
	Voice Basket	MBB Basket	Voice Basket	MBB Basket	Voice Basket	MBB Basket
Spectrum price						
Average effect	0.000776***	0.00236***	0.000976**	0.00240***	-1.391	1.102
	(0.000205)	(0.000263)	(0.000374)	(0.000338)	(1.862)	(1.273)
Controls						
HHI	-9.94e-05**	0.000182***	-0.000203***	0.000136	-2.07e-05	0.000236***
	(4.27e-05)	(6.05e-05)	(4.58e-05)	(0.000116)	(3.66e-05)	(6.27e-05)
GDP per capita	-5.15e-06	-1.47e-05	1.28e-05	3.71e-05	-1.18e-05*	-1.74e-05
	(8.98e-06)	(1.28e-05)	(6.38e-05)	(3.78e-05)	(6.32e-06)	(1.10e-05)
Urban population %	-0.0117	0.0786	-0.00432	0.113*	-0.0181	-0.0335
	(0.0684)	(0.0514)	(0.0653)	(0.0582)	(0.0849)	(0.137)
Population density	0.000882**	0.000928	0.0478***	0.00682	0.000778*	0.000586
	(0.000416)	(0.00127)	(0.0164)	(0.00868)	(0.000447)	(0.00140)
Constant	3.956	-3.389	-0.475	-5.671	4.588	4.794
	(4.907)	(3.787)	(3.616)	(4.260)	(6.692)	(10.80)
Country FE	yes	yes	yes	yes	yes	yes
Time FE	yes	yes	yes	yes	yes	yes
Observations	327	296	139	125	188	171
R-squared	0.786	0.706	0.905	0.799	0.700	0.678

Cluster-robust standard errors in parentheses

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

Figure A1.51

OLS REGRESSION RESULTS USING LOG OF PRICE $/MHZ/POP/LICENCE YEAR

Log of basket price ($PPP)

	All countries		Developing		Developed	
	Voice Basket	MBB Basket	Voice Basket	MBB Basket	Voice Basket	MBB Basket
Spectrum price						
Average effect	-0.00984	-0.0449	-0.0709	-0.0199	0.0117	-0.0381
	(0.0418)	(0.0770)	(0.0491)	(0.124)	(0.0322)	(0.0965)
Controls						
HHI	-0.000104**	0.000408**	-0.000135**	0.000621**	-3.46e-05	0.000225***
	(4.35e-05)	(0.000177)	(5.02e-05)	(0.000226)	(3.30e-05)	(7.70e-05)
GDP per capita	-3.90e-06	-2.60e-05*	-1.66e-06	9.17e-06	-8.60e-06	-2.29e-05
	(9.40e-06)	(1.46e-05)	(7.03e-05)	(6.35e-05)	(6.97e-06)	(1.43e-05)
Urban population %	-0.00634	-0.0538	-0.0125	0.0293	-0.0330	-0.0251
	(0.0605)	(0.107)	(0.0751)	(0.0985)	(0.0901)	(0.141)
Population density	0.00111**	-0.00196	0.0346**	-0.0492**	0.000784	-0.00132
	(0.000498)	(0.00209)	(0.0151)	(0.0230)	(0.000500)	(0.00190)
Constant	3.320	6.305	0.760	2.689	5.467	5.428
	(4.443)	(7.439)	(3.812)	(6.717)	(7.148)	(11.28)
Country FE	yes	yes	yes	yes	yes	yes
Time FE	yes	yes	yes	yes	yes	yes
Observations	355	317	153	136	202	181
R-squared	0.786	0.692	0.891	0.775	0.721	0.681

Cluster-robust standard errors in parentheses

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

Figure A1.52

INSTRUMENTAL VARIABLE REGRESSION RESULTS USING LOG OF $PPP/MHZ/POP/LICENCE YEAR

	Log of voice basket price (PPP)					
	All countries		Developing		Developed	
	First stage	Second stage	First stage	Second stage	First stage	Second stage
Instruments						
Short-term debt	-0.00854		0.0151			
	(0.0157)		(0.0192)			
Non-auction assignment	-1.087***				-1.063***	
	(0.315)				(0.332)	
Spectrum price in region	1.061*				1.195	
	(0.555)				(0.730)	
Reserve price in region	-0.0816				-0.0904	
	(0.221)				(0.306)	
Spectrum price						
Average effect		-0.127		1.468		-0.128
		(0.108)		(1.824)		(0.121)
Controls						
HHI	0.000439**	-0.000123*	0.000140	-0.000369*	0.000310	-8.96e-06
	(0.000193)	(7.13e-05)	(0.000113)	(0.000222)	(0.000190)	(5.92e-05)
GDP per capita	-5.85e-05***	-1.15e-05	-7.18e-05	0.000139	-6.69e-05***	-1.79e-05
	(1.95e-05)	(1.02e-05)	(6.14e-05)	(0.000148)	(2.11e-05)	(1.14e-05)
Urban population %	-0.0395	-0.0494	-0.0596	0.0794	0.00488	-0.0599
	(0.114)	(0.0434)	(0.113)	(0.230)	(0.452)	(0.0951)
Population density	0.000819	0.000910*	0.00332	0.0487*	0.000896	0.000705
	(0.000928)	(0.000475)	(0.0203)	(0.0276)	(0.00122)	(0.000476)
Constant	-341.1**	70.20	-644.1***	1,325	-356.2	27.34
	(136.8)	(77.56)	(208.6)	(1,349)	(220.4)	(94.52)
Country FE	yes	yes	yes	yes	yes	yes
Time FE	yes	yes	yes	yes	yes	yes
Observations	288		131		189	
Under identification p-value[1]	0.000		0.398		0.008	
Weak identification p-value[2]	0.000		0.434		0.006	
Weak identification F-Statistic[3]	5.455		0.618		4.337	
Overidentification p-value[4]	0.045		N/A		0.227	
Endogeneity p-value[5]	0.231		0.005		0.304	

Cluster-robust standard errors in parentheses

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

1. Reports the p-value of the Kleibergen-Paap rk LM statistic. Null hypothesis is that the model is underidentified.
2. Reports the p-value of the Sanderson-Windmeijer statistic. Null hypothesis is that the model is weakly identified.
3. Reports the Kleibergen-Paap Wald rk F-statistic for weak identification.
4. Reports the p-value of the Hansen's J statistic where more than one instrument is used. Joint null hypothesis is that the instruments are valid and not correlated with the error term.
5. Reports the p-value of the endogeneity test (C statistic). Null hypothesis is that the endogenous regressors are in fact exogenous.

Figure A1.53

INSTRUMENTAL VARIABLE REGRESSION RESULTS USING LOG OF $PPP/MHZ/POP/LICENCE YEAR

Log of mobile broadband basket price (PPP)

	All countries		Developing		Developed	
	First stage	Second stage	First stage	Second stage	First stage	Second stage
Instruments						
Short-term debt	-0.00157		0.0275*			
	(0.0148)		(0.0165)			
Non-auction assignment	-0.966***				-0.865**	
	(0.362)				(0.349)	
Spectrum price in region	0.525*				0.585	
	(0.283)				(0.401)	
Reserve price in region	0.0943				0.0911	
	(0.137)				(0.183)	
Spectrum price						
Average effect		-0.0599		-1.834		-0.155
		(0.113)		(3.904)		(0.137)
Controls						
HHI	0.000395*	3.13e-05	0.000265*	0.00326*	0.000290	9.36e-05
	(0.000218)	(0.000115)	(0.000136)	(0.00178)	(0.000178)	(0.000103)
GDP per capita	-6.93e-05***	-1.98e-05	-9.25e-05**	-0.000388	-8.03e-05***	-2.84e-05
	(1.80e-05)	(1.97e-05)	(4.46e-05)	(0.000726)	(2.03e-05)	(2.21e-05)
Urban population %	-0.117	0.0133	0.0794	0.960	-0.400**	-0.157
	(0.0740)	(0.0501)	(0.0657)	(0.689)	(0.198)	(0.143)
Population density	-0.000818	-0.00241*	0.00897	0.0309	-0.00166	-0.00283**
	(0.00130)	(0.00126)	(0.0184)	(0.192)	(0.00142)	(0.00139)
Constant	-433.3***	108.1	-420.6***	1,177	-551.0***	12.42
	(111.1)	(110.3)	(98.35)	(2,298)	(130.9)	(145.6)
Country FE	yes	yes	yes	yes	yes	yes
Time FE	yes	yes	yes	yes	yes	yes
Observations	266		117		171	
Under identification p-value[1]	0.003		0.109		0.017	
Weak identification p-value[2]	0.006		0.099		0.020	
Weak identification F-Statistic[3]	3.692		2.784		3.403	
Overidentification p-value[4]	0.221		N/A		0.082	
Endogeneity p-value[5]	0.765		0.626		0.529	

Cluster-robust standard errors in parentheses

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

1. Reports the p-value of the Kleibergen-Paap rk LM statistic. Null hypothesis is that the model is underidentified.
2. Reports the p-value of the Sanderson-Windmeijer statistic. Null hypothesis is that the model is weakly identified.
3. Reports the Kleibergen-Paap Wald rk F-statistic for weak identification.
4. Reports the p-value of the Hansen's J statistic where more than one instrument is used. Joint null hypothesis is that the instruments are valid and not correlated with the error term.
5. Reports the p-value of the endogeneity test (C statistic). Null hypothesis is that the endogenous regressors are in fact exogenous.

Figure A1.54

ARELLANO-BOND REGRESSION RESULTS USING LOG OF PRICE $/MHZ/POP/LICENCE YEAR

Log of voice basket price (PPP)

	All countries				Developing	
	(1)	(2)	(3)	(4)	(5)	(6)
Spectrum price						
Average effect	-0.0736	-0.0145	-0.0262	0.0178	-0.398	-0.203
	(0.102)	(0.0698)	(0.0490)	(0.0619)	(0.313)	(0.260)
Controls						
$Price_{t-1}$	0.292	0.236	0.718***	0.783***	0.223	0.225
	(0.226)	(0.238)	(0.101)	(0.113)	(0.168)	(0.180)
HHI	-4.16e-05	-4.50e-05	-3.22e-05	-2.12e-05	-4.57e-05	1.40e-05
	(7.05e-05)	(6.66e-05)	(3.27e-05)	(4.33e-05)	(9.25e-05)	(7.45e-05)
GDP per capita	-1.38e-06	-1.75e-06	1.11e-08	-8.00e-07	-5.22e-05	-3.80e-05
	(8.02e-06)	(6.47e-06)	(1.28e-06)	(1.21e-06)	(3.14e-05)	(4.45e-05)
Urban population %	-0.105*	-0.125*	0.00176	0.00137	0.00155	0.00762
	(0.0526)	(0.0630)	(0.00138)	(0.00158)	(0.111)	(0.0800)
Population density	0.000237	-5.78e-05	-3.24e-05	-2.58e-05	0.0388	0.0262
	(0.000721)	(0.000571)	(2.29e-05)	(2.62e-05)	(0.0240)	(0.0304)
Difference or system GMM	Difference	Difference	System	System	Difference	Difference
Estimator	One-step	Two-step	One-step	Two-step	One-step	Two-step
Observations	192	192	247	247	67	67
Number of groups	54	54	55	55	23	23
Number of instruments	17	17	28	28	16	16
AR(1) p-value[1]	0.126	0.159	0.002	0.001	0.163	0.206
AR(2) p-value[2]	0.343	0.319	0.255	0.234	0.291	0.330
Overidentification p-value[3]	0.416	0.416	0.437	0.437	0.429	0.429

Cluster-robust standard errors in parentheses

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

1. Reports the p-value of the Arellano-Bond test for AR(1) in first differences. Null hypothesis is that there is no autocorrelation.
2. Reports the p-value of the Arellano-Bond test for AR(2) in first differences. Null hypothesis is that there is no autocorrelation.
3. Reports the p-value of the Hansen's J statistic. Null hypothesis is that the instruments as a group are exogenous.

Figure A1.54 (cont.)

ARELLANO-BOND REGRESSION RESULTS USING LOG OF PRICE $/MHZ/POP/LICENCE YEAR (cont.)

	Log of voice basket price (PPP)					
	Developing		Developed			
	(7)	(8)	(9)	(10)	(11)	(12)
Spectrum price						
Average effect	0.0195	0.0300	-0.112	-0.0691	-0.0757	-0.00548
	(0.0558)	(0.0680)	(0.0932)	(0.0576)	(0.0835)	(0.0578)
Controls						
$Price_{t-1}$	0.776***	0.791***	-0.402	-0.480**	0.713***	0.769***
	(0.0972)	(0.120)	(0.356)	(0.200)	(0.163)	(0.0697)
HHI	-6.31e-06	-1.66e-05	3.13e-05	1.64e-05	1.30e-05	-6.46e-06
	(4.11e-05)	(5.77e-05)	(7.14e-05)	(6.37e-05)	(3.71e-05)	(3.10e-05)
GDP per capita	3.66e-06	4.30e-06	-1.17e-05	-1.09e-05	2.36e-06	7.34e-07
	(7.29e-06)	(8.62e-06)	(1.31e-05)	(1.05e-05)	(2.31e-06)	(2.58e-06)
Urban population %	-0.00296	-0.00276	-0.325**	-0.200*	0.00406*	0.00447
	(0.00265)	(0.00397)	(0.154)	(0.104)	(0.00232)	(0.00300)
Population density	-0.00119	-0.00107	0.000616	0.000726	-3.53e-05	-3.43e-05**
	(0.00112)	(0.00161)	(0.00101)	(0.00119)	(2.29e-05)	(1.65e-05)
Difference or system GMM	System	System	Difference	Difference	System	System
Estimator	One-step	Two-step	One-step	Two-step	One-step	Two-step
Observations	91	91	128	128	160	160
Number of groups	24	24	32	32	32	32
Number of instruments	27	27	16	16	27	27
AR(1) p-value[1]	0.047	0.047	0.507	0.216	0.008	0.005
AR(2) p-value[2]	0.454	0.464	0.931	0.889	0.405	0.351
Overidentification p-value[3]	0.543	0.543	0.876	0.876	0.736	0.736

Figure A1.55

ARELLANO-BOND REGRESSION RESULTS USING LOG OF PRICE $/MHZ/POP/LICENCE YEAR

Log of mobile broadband basket price (PPP)

	All countries				Developing	
	(1)	(2)	(3)	(4)	(5)	(6)
Spectrum price						
Average effect	0.0576	0.0400	0.0134	0.0489	-0.0757	-0.0956
	(0.138)	(0.137)	(0.109)	(0.102)	(0.216)	(0.198)
Controls						
$Price_{t-1}$	0.215	0.100	0.563***	0.550***	-0.212	-0.304
	(0.147)	(0.185)	(0.134)	(0.159)	(0.339)	(0.380)
HHI	-0.000354*	-0.000338	3.22e-07	1.88e-05	0.000153	0.000124
	(0.000180)	(0.000237)	(5.30e-05)	(7.40e-05)	(0.000122)	(0.000151)
GDP per capita	-4.97e-05**	-4.20e-05*	-2.83e-06	-2.89e-06	-4.07e-05	-5.82e-05
	(1.87e-05)	(2.32e-05)	(2.24e-06)	(2.54e-06)	(3.50e-05)	(7.73e-05)
Urban population %	0.0226	-0.00838	0.00429	0.00520	0.105*	0.0750
	(0.0682)	(0.0726)	(0.00292)	(0.00413)	(0.0574)	(0.0688)
Population density	-0.00144	-0.00218*	-1.62e-05	-2.60e-05	-0.0290**	-0.0270**
	(0.00108)	(0.00123)	(2.91e-05)	(2.97e-05)	(0.0126)	(0.0126)
Difference or system GMM	Difference	Difference	System	System	Difference	Difference
Estimator	One-step	Two-step	One-step	Two-step	One-step	Two-step
Observations	163	163	218	218	56	56
Number of groups	54	54	55	55	23	23
Number of instruments	15	15	24	24	14	14
AR(1) p-value[1]	0.080	0.418	0.036	0.059	0.935	0.681
AR(2) p-value[2]	0.087	0.341	0.073	0.097	0.639	0.984
Overidentification p-value[3]	0.163	0.163	0.164	0.164	0.242	0.242

Cluster-robust standard errors in parentheses

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

1. Reports the p-value of the Arellano-Bond test for AR(1) in first differences. Null hypothesis is that there is no autocorrelation.
2. Reports the p-value of the Arellano-Bond test for AR(2) in first differences. Null hypothesis is that there is no autocorrelation.
3. Reports the p-value of the Hansen's J statistic. Null hypothesis is that the instruments as a group are exogenous.

Figure A1.55 (cont.)

ARELLANO-BOND REGRESSION RESULTS USING LOG OF PRICE $/MHZ/POP/LICENCE YEAR (cont.)

	Log of mobile broadband basket price (PPP)					
	Developing		Developed			
	(7)	(8)	(9)	(10)	(11)	(12)
Spectrum price						
Average effect	-0.0238	-0.0141	0.266	0.184	0.0370	-0.0194
	(0.0767)	(0.0927)	(0.173)	(0.254)	(0.116)	(0.114)
Controls						
$Price_{t-1}$	0.723***	0.741***	0.310	-0.0546	0.569***	0.569***
	(0.109)	(0.130)	(0.215)	(0.224)	(0.137)	(0.104)
HHI	4.80e-06	-1.01e-05	-2.59e-05	0.000101	-4.74e-05	-1.84e-05
	(5.47e-05)	(9.20e-05)	(0.000188)	(0.000230)	(5.65e-05)	(4.11e-05)
GDP per capita	6.31e-06	7.08e-06	-4.66e-05**	-3.95e-05	-5.92e-07	3.73e-07
	(5.58e-06)	(4.79e-06)	(2.05e-05)	(2.64e-05)	(3.64e-06)	(2.97e-06)
Urban population %	-0.00107	-0.00204	0.0525	-0.241	0.00438	0.00486
	(0.00326)	(0.00535)	(0.230)	(0.220)	(0.00415)	(0.00373)
Population density	-0.00202*	-0.00236	-0.00170	-0.00322*	-3.02e-05	-1.88e-05
	(0.00101)	(0.00152)	(0.00150)	(0.00176)	(3.60e-05)	(3.12e-05)
Difference or system GMM	System	System	Difference	Difference	System	System
Estimator	One-step	Two-step	One-step	Two-step	One-step	Two-step
Observations	80	80	110	110	142	142
Number of groups	24	24	32	32	32	32
Number of instruments	23	23	14	14	23	23
AR(1) p-value[1]	0.052	0.058	0.083	0.974	0.049	0.065
AR(2) p-value[2]	0.047	0.049	0.329	0.545	0.100	0.132
Overidentification p-value[3]	0.412	0.412	0.209	0.209	0.383	0.383

Annex 2: Data and sources

Variable name	Description	Source	Scope
Spectrum price, $PPP/MHz/pop/year	Spectrum price normalised by MHz, population and licence length	GSMA Intelligence	Quarterly (2010–2017)
Spectrum price, percentage of current revenues	Spectrum price normalised by current revenues, MHz and licence length	GSMA Intelligence	Quarterly (2010–2017)
Spectrum price, percentage of future revenues	Spectrum price normalised by 10-year future revenues and MHz	GSMA Intelligence and Damodaran Online	Quarterly (2010–2017)
4G spectrum	Amount of spectrum holdings in bands that can be used for 4G services	GSMA Intelligence	Quarterly (2010–2017)
3G spectrum	Amount of spectrum holdings in bands that can be used for 3G services	GSMA Intelligence	Quarterly (2010–2017)
4G spectrum X-Y years	Dummy variable indicating whether operator has had 4G spectrum between X and Y years	GSMA Intelligence	Quarterly (2010–2017)
3G spectrum X-Y years	Dummy variable indicating whether operator has had 3G spectrum between X and Y years	GSMA Intelligence	Quarterly (2010–2017)
4G coverage	4G coverage (based on proportion of population covered)	GSMA Intelligence	Quarterly (2010–2017)
3G coverage	3G coverage (based on proportion of population covered)	GSMA Intelligence	Quarterly (2010–2017)
All/3G/4G download speeds	Average download speeds for all/3G/4G technologies	Ookla's Speedtest	Quarterly (2011–2017)
All/3G/4G upload speeds	Average upload speeds for all/3G/4G technologies	Ookla's Speedtest	Quarterly (2011–2017)
All/3G/4G latencies	Average latencies speeds for all/3G/4G technologies	Ookla's Speedtest	Quarterly (2011–2017)
ARPU (log)	Recurring revenues (in $PPP) divided by number of connections	GSMA Intelligence	Quarterly (2010–2017)
Voice basket price (log)	Price (in $PPP) of 'mobile-cellular sub-basket' or 'voice basket' of 30 outgoing calls per month and 100 SMS messages	ITU	Annual (2011–2017)
Mobile broadband basket price (log)	Price (in $PPP) of 'mobile broadband basket' of 500 MB per month (based on pre-paid tariffs)	ITU	Annual (2012–2017)
HHI (log)	Sum of the square the market shares (based on connections) of each operator competing in a country	GSMA Intelligence	Quarterly (2010–2017)
Market share	Market share based on % of total connections	GSMA Intelligence	Quarterly (2010–2017)
GDP per capita (log)	GDP per capita in $PPP	World Bank	Quarterly (2010–2017)*
Rural population	Percentage of population living in rural areas	World Bank	Quarterly (2010–2017)*
Population density (log)	Population per square km of land	World Bank	Quarterly (2010–2017)*

Variable name	Description	Source	Scope
Smartphone adoption	Number of smartphone connections divide by population	GSMA Intelligence	Quarterly (2010–2017)
Coverage obligations	Dummy variable indicating whether operator has acquired a spectrum licence with coverage obligations	GSMA Intelligence	Quarterly (2010–2017)
Quality of service obligations	Dummy variable indicating whether operator has acquired a spectrum licence with quality of service obligations	GSMA Intelligence	Quarterly (2010–2017)
Short-term debt	Central government debt maturing in 12 months or less (as a % of GDP)	World Bank	Quarterly (2010–2017)*
Non-auction	Dummy variable indicating whether a spectrum licence was not assigned by auction	GSMA Intelligence	Quarterly (2010–2017)
Spectrum price in region, $PPP/MHz/pop/year	Average spectrum price in region (Asia-Pacific, CIS, Europe, Latin America, MENA and Sub-Saharan Africa)	GSMA Intelligence	Quarterly (2010–2017)
Reserve price in region, $PPP/MHz/pop/year	Average reserve price in region (Asia-Pacific, CIS, Europe, Latin America, MENA and Sub-Saharan Africa)	GSMA Intelligence	Quarterly (2010–2017)

Source: GSMA Intelligence

* The original data is annual. We have used linear interpolation to obtain quarterly estimates.

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