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The dynamic effects of competition on investment: the case of the European mobile communications industry

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The dynamic effects of competition on investment: the case of the European mobile communications industry

Bahia, Calvin; Castells, Pau

2022

Abstract

We evaluate the impact of competition on investments in Europe's mobile communications market during the 2011-2021 period. There are stark and sustained differences in market outcomes between three- and four-player markets in Europe, and economic theory suggests these could be partly explained by the dynamic effects of competition on the ability and incentives to invest by market players. We find strong evidence that market concentration in Europe is below optimal levels that would maximise investments, especially in four-player markets. The dispersion of fixed costs and assets among a greater number of players can result in diseconomies of scale and a less efficient use of resources. We also find evidence that investment incentives to improve quality and innovate are lower in markets with lower concentration indices and profit margins.

JEL Classifications: K20 - General; L10 - General; L40 - General; L96 - Telecommunications

1. Background

One of the key drivers of investment in the mobile sector is competition. Both economic theory and the empirical literature have highlighted the important balance that needs to be considered between competition and investment. On the one hand, mobile networks are characterised by large fixed and common costs, which means larger players with greater scale may drive more efficient investments. Furthermore, it is possible that in more concentrated mobile markets, firms may have a greater incentive to increase investment (as well as greater ability) because of the potential for higher returns. On the other hand, as market concentration decreases, it can drive greater competition between firms. This can create an incentive to invest more in better quality networks and/or new products and services, as a way of differentiating the firm from other competitors and thereby winning and retaining customers.

It is clear that the optimal market structure in mobile communications is not a one-firm monopoly, given this would remove any incentive to innovate and invest in improving quality. Similarly, it is obvious that no country could sustain a very large number of mobile networks, given the need for a minimum efficient scale and the risk of network duplication and inefficiencies it would involve, in addition to low financial returns that would disincentivise investment. However, it is less clear where the optimal balance lies and how this might vary based on country- and market-specific factors. The question around what market structure optimises investment in the mobile sector has been a live issue in Europe during the past decade. Since 2010, mobile operators have sought to reduce network costs and improve efficiency either by engaging in network sharing or through market consolidation, via mergers and acquisitions. There have been seven approved mergers in Europe since 2010¹ – in the United Kingdom, Austria, Ireland, Germany, Norway, Italy and the Netherlands. In the same period, there have also been four major entries into European mobile markets – in France, the Netherlands, Italy and Slovakia. Europe's chief competition authority, the Directorate General for Competition of the European Commission, also rejected a proposed merger in the United Kingdom on the grounds that the competition concerns outweighed the perceived potential benefits². Additionally, a proposed merger was withdrawn in Denmark on the expectation that the European Commission would not clear it without significant remedies.³

The EU General Court (GC) annulment of the European Commission's (EC) decision to block the Three/O2 merger in the UK further highlighted the debate about consolidation in the mobile sector.⁴ More recently, European operators brought the issue back into focus by stressing the need for certain markets to consolidate in order to boost investment in the sector and accelerate the roll-out of 5G.⁵ For

¹ The data we study covers 29 European countries – 26 out of the 27 members of the European Union along with the UK, Norway and Switzerland (Cyprus was not used due to the existence of two practical mobile markets on the island). We included operators that had a market share greater than 3 per cent at some point in the period of analysis. This was for two reasons: (i) to ensure that we only took into account operators with a significant presence in the national market, and; (ii) to ensure that the operators in our sample had sufficient network quality data. The operators included in our analysis accounted for more than 99% of mobile connections in the 29 countries over the period.

² http://ec.europa.eu/competition/mergers/cases/decisions/m7612_6555_3.pdf

³ https://europa.eu/rapid/press-release_STATEMENT-15-5627_en.htm

⁴ At the time of writing, this decision is being challenged and is expected to be heard at the European Court of Justice.

⁵ See for example <https://www.mobileworldlive.com/featured-content/top-three/vodafone-chief-hints-at-deals-in-europe>

example, Orange and MasMovil entered into discussions to combine their Spanish businesses in March 2022, while Vodafone and Three entered into talks to merge its UK operations in May 2022.⁶

The mobile telecommunications market in Europe is at the start of a significant investment phase in fifth generation (5G) networks. In January 2022, commercial 5G was available in all 27 EU member states, as well as in the UK, Switzerland and Norway. The key objective, as articulated in the EU Commission's 5G Action plan⁷ and the EU Digital Decade⁸, is to achieve uninterrupted 5G broadband coverage for all urban areas and major roads and railways by 2025 and for all populated areas to be covered with 5G by 2030. The Commission has also stated that 5G should be at the core of new products, manufacturing processes and business models by the end of the decade. The outbreak of the Covid-19 pandemic has only accelerated the need to deploy 5G and enable its use, given the reliance of businesses, the public sector, schools and wider society on fast and reliable connectivity.

An important driver of 5G is whether operators in Europe have the incentive and ability to make the investments that are necessary to achieve the 5G targets that have been set. The roll-out of 5G will incur higher deployment costs than 4G, primarily due to the need for more sites and spectrum. It has been estimated that the number of sites needed for 5G will increase by 50% when compared to previous network generations, while a report by the European Court of Auditors suggests that the total deployment cost of 5G across all EU member states could reach €400 billion. On the demand side, it remains uncertain as to how much additional revenue operators will gain from 5G. While mobile internet use has increased exponentially over the past decade and networks have had to manage the higher traffic volumes (which is expected to continue with 5G), operator revenues in most European countries have been relatively flat or have declined.

It is in this context that we seek to investigate the relationship between competition and market outcomes. It focuses on how competition dynamics in Europe impacted investment and mobile network performance during the 2011-2021 period, a period that saw the roll-out of 4G networks, as well as the emergence of 5G.

⁶ <https://www.mobileworldlive.com/featured-content/home-banner/orange-moves-on-masmovil-merger-plan> and <https://www.mobileworldlive.com/featured-content/home-banner/vodafone-talks-merger-with-3-uk>

⁷ See <https://digital-strategy.ec.europa.eu/en/policies/5g-action-plan>

⁸ See <https://digital-strategy.ec.europa.eu/en/policies/5g-digital-decade>

2. Literature review

The measurement of 'competition' has been the subject of extensive debate in the economics literature. It has historically been measured using indicators such as the number of players, measures of market concentration (e.g. market shares and HHI), entry/exit rates, profitability or the Lerner Index, to cite a few. These all capture different aspects of competition, though it is difficult to produce a complete assessment of such a complex and multi-dimensional concept.⁹

Furthermore, the interpretation of such measures often differs, with some economists arguing that greater concentration and profits might reflect greater efficiency and innovation, while others argue that they reflect greater market power, increases in barriers to entry and less dynamic competition. In reality, depending on time and place, it is plausible that the same indicators can reflect all of the above, even at the same time. This debate reflects the complex relationship that exists between the number of players or concentration in a market and outcomes such as quality, innovation and prices. Economic theory suggests that an increase in market concentration can have both positive and/or negative effects on consumers, and that it depends on the particular circumstances of the market, the incentives of players and consumer attitudes to products and services. In this respect, it is important to distinguish "competition" or "market power" from concepts such as "concentration" or "profit", as greater concentration/profit is not always associated with less market competition or more market power (or vice versa).¹⁰

It is also important to note that changes in market concentration may not necessarily be causally linked to market outcomes such as price or quality, rather it is the underlying features of a market that impact both concentration and outcomes. These features include the cost structure of different firms, the number of firms, their strategic focus, expected returns and consumer demand – together they determine the level of concentration, price and service quality that exists in the market equilibrium. As it is not possible to measure all of these factors precisely, in the context of the mobile sector, the key question is whether having more (or less) players or smaller (or larger) firms impacts the cost structure of operators, their use of assets, expected returns and dynamic competitive conditions in such a manner that they then drive a change in market outcomes.

There is an abundance of theoretical and empirical literature examining the relationship between concentration and consumer welfare, both generally and in the mobile telecommunications sector.¹¹ Lower market concentration indices can be associated with greater incentives to lower prices and improve quality of service, if it means firms compete more intensely to win and retain customers.¹² However, low concentration levels can generate dynamics that cancel out these positive competitive effects, especially in a sector such as mobile where firms face large fixed and common costs.¹³ In particular, market structures with a larger number of operators can undermine operators' scale, push up average deployment costs, reduce network capacity and decrease margins and returns on

⁹ For a further discussion of different competition metrics, see OECD (2021)

¹⁰ See OECD (2021) for further discussion.

¹¹ For a more extensive review, see Genakos et al (2018) and Fruits et al (2019)

¹² See for example Motta and Tarantino (2021) and Federico et al (2018)

¹³ See for example Jullien and Lefouilli (2018) and Borreau and Jullien (2017)

investment. This can reduce the ability and incentive to invest in improving network coverage, quality and innovation, and limit operators' ability to minimise costs.

A key question for regulators and policy-makers is therefore to understand what is the level of concentration that will optimise investment in the mobile sector and maximise consumer welfare. This is particularly important for general purpose technologies like mobile communications, as the effects of investments spill-over to most other sectors of the economy and generate productivity growth¹⁴. There has been extensive empirical research carried out on this topic during the past ten years. While much of the research on the effect of concentration on prices is inconclusive, the evidence has largely shown that more concentrated markets drive greater investment at the operator-level (see Annex 1 for a summary of the literature). No study to date has found that higher market concentration reduces operator investment, while the majority of studies have found that country-level investment is not significantly impacted by market concentration.¹⁵ More recent empirical studies have also found a positive impact of mergers, operator scale and more concentrated markets on network coverage and speeds.¹⁶ Where this is associated with greater investments by operators, it would mean that some of the efficiencies generated by higher market concentration are being passed onto consumers.

The evidence with regard to pricing impacts is mixed, with some studies suggesting mergers or increased concentration can increase consumer prices¹⁷ while others suggest they can drive price reductions.¹⁸ The different findings are often due to the choice of pricing metric, the scope of the analysis (time period and the countries being considered) and the methodologies employed (see Annex 1).

Another way in which operators can reduce costs is to engage in network sharing, including roaming, passive, active and spectrum sharing. This involves the sharing of infrastructure between two competing operators, with the intention to reduce costs, improve coverage and quality and/or achieve faster roll-out of new technology. The presence of network sharing means that concentration will vary at the wholesale and retail levels. For example, in a market with four operators, if there are two active MORAN¹⁹ network sharing agreements, the concentration of passive and active networks (responsible for the radio access equipment) will be higher than at the retail (consumer) level. Koutroumpis et al (2021) found that during the 2000-2019 period, increased network sharing in Europe enabled operators to reduce costs and generate higher returns – and this resulted in lower prices and improved network coverage and quality for consumers.

¹⁴ See for example Bertschek et al (2017)

¹⁵ See for example Genakos et al (2018) and GSMA (2020)

¹⁶ See for example GSMA (2017)

¹⁷ See for example Genakos et al (2018) and Aguzzoni et al (2018)

¹⁸ See for example Hounghonon and Jeanjean (2019)

¹⁹ Multi-Operator Radio Access Network

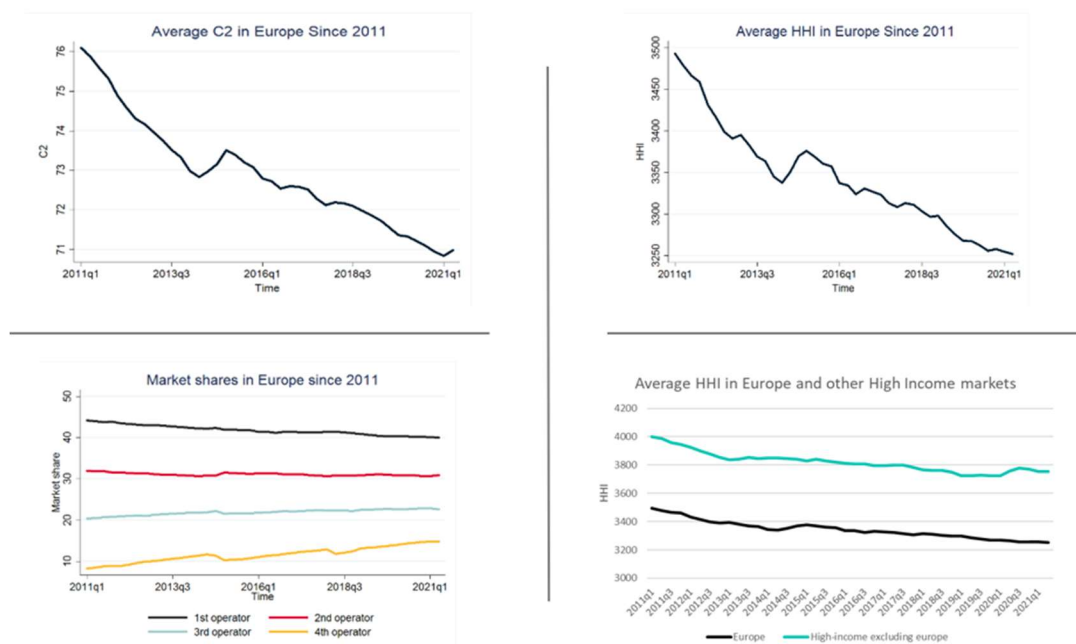
3. Competition dynamics in European mobile markets

We analysed quarterly mobile market data in the decade between Q1 2011 and Q2 2021 (further detail on the datasets used is provided in Annex 2). The analysis covers 104 operators in 29 European countries – 26 out of the 27 members of the European Union²⁰ along with the United Kingdom, Norway and Switzerland.

In this period, European markets experienced on average a decline in market concentration as measured by HHI²¹ and C2²². In fact, at the end of the period, concentration levels in Europe stood significantly below the rest of the world, with an average HHI of 3250 compared with almost 5000 globally. Furthermore, while from 2015 onwards global levels of market concentration in mobile markets remained stable, in Europe they continued to decline, meaning that the gap became larger during the period of analysis. During this period Europe also sustained a 500 points-gap with the higher HHI values observed in other high-income countries.

Further inspection of the drivers of this change suggest that the decline in overall market concentration was primarily driven by a reduction in the average market shares of the top-two operators in European markets. In turn, this was mostly caused by the growth of smaller players (3rd and 4th operators) and, in a more limited number of markets, by the effects of market entry.

Figure 1: Market concentration trends in Europe



²⁰ Cyprus was not used due to the existence of two practical mobile markets on the island

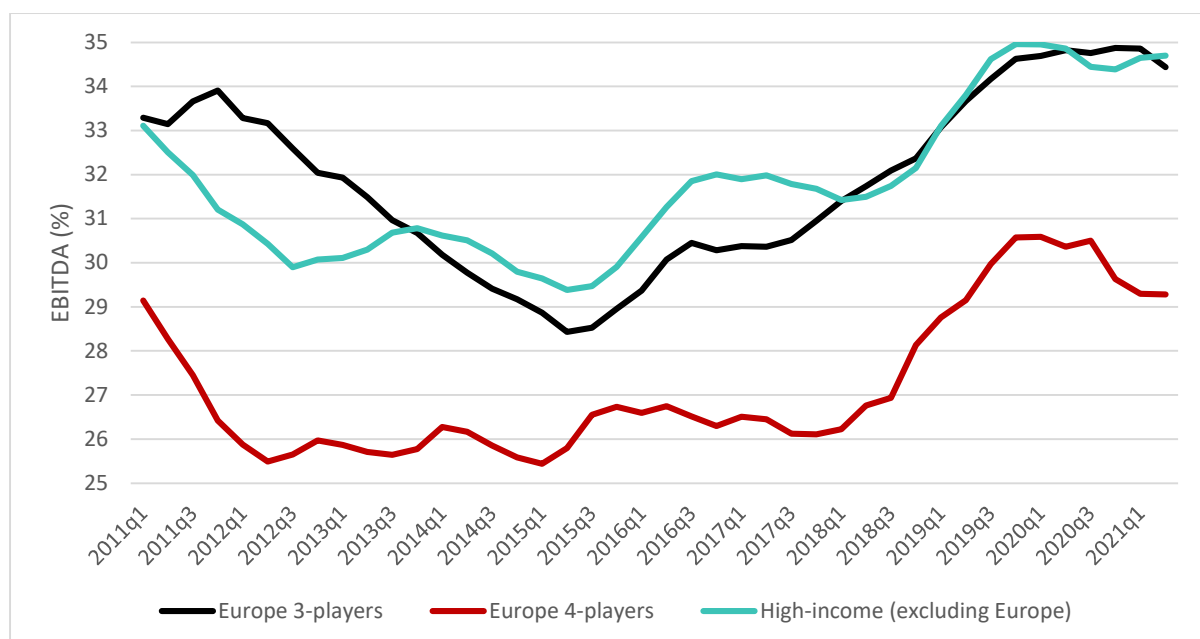
²¹ HHI or Herfindahl-Hirschman Index is the primary measure of market concentration with values between 0 and 10,000, increasing values suggesting a higher level of market concentration. The index is formed by summing the squares of individual operator market shares within each market – the functional form has the impact of skewing higher results to market where individual operators have very high market shares.

²² The Concentration Ratio-2 (CR2) measures the market shares of the two largest firms in the market.

Source: GSMA Intelligence. High-income countries excluding Europe are based on 2021 World Bank Income classifications.²³

Coupled with the reduction in market concentration, the period in Europe was also characterised by profit margins that remained significantly below global levels. This was particularly the case in European 4-player markets, with EBITDA margins in the period fluctuating between 25-30%, compared to a global average of 35-40%. In the case of European 3-player markets, margins also remained throughout the period below the levels observed outside of the region. However, they were consistently higher than in European 4-player markets and were comparable to profitability in other high-income markets.

Figure 2: EBITDA Margins



Source: GSMA Intelligence.

In addition to market profitability, margins can also help understand the strength of static and dynamic competitive intensity²⁴ in the market. On one hand, relatively low margins can point to the possible strength of static competition forces in European mobile markets, where profits are kept low through strong competition for market share among market players. On the other hand, relatively low concentration and profit margins can also point to weak conditions for dynamic competition. In mobile markets, dynamic competition can be linked in particular to the ability and capacity to carry out

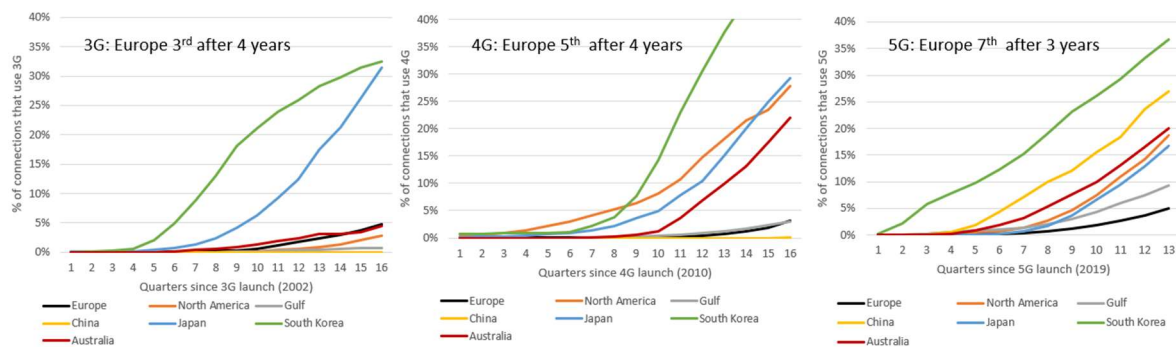
²³ The high-income countries include Australia, Bahrain, Brunei, Canada, Chile, Israel, Japan, South Korea, Kuwait, New Zealand, Oman, Panama, Qatar, Saudi Arabia, Singapore, UAE, USA and Uruguay.

²⁴ Profit margins are a financial measure that proxies a firm's accounting profits. As such, they are not always a perfect proxy for economic profits, which should take into account not historical costs, but the opportunity costs from the inputs required. In particular, in capital intensive industries like mobile communications, EBITDA margins do not take into account the amortisation and depreciation of capital investments. However, over time, sustained differences and trends across countries in EBITDA margins are expected to reflect underlying actual differences in profitability and therefore on the ability and incentives to undertake investments in the market. Furthermore in the context of our study, a measure that captures the profits before accounting for the amortisation of capital investments allows us to understand whether higher pre-amortization profits increase the ability to undertake greater investments in network quality or new services and products.

investments that bring forward innovation (for example 5G, which can reduce unit costs and deliver new services) or product differentiation (better quality and services for consumers).

Weaker dynamic competition incentives in Europe could also be linked to the initial differences observed in the roll-out of 5G networks: trends show how Europe has increasingly lagged behind its economic peers since the '4G era'. With the exception of South Korea and Japan, the adoption of 3G in Europe in the first four years was either at a similar level or higher than other developed economies. The adoption of 4G in Europe followed a similar path to 3G, but other markets including North America and Australia saw much faster growth. Since 5G launched at the start of 2019, adoption has increased even faster than previous technologies across all high-income countries – but Europe has lagged further behind not just the '4G leaders' but also China and countries in the Gulf, which have made determined efforts to drive 5G forward in their markets.

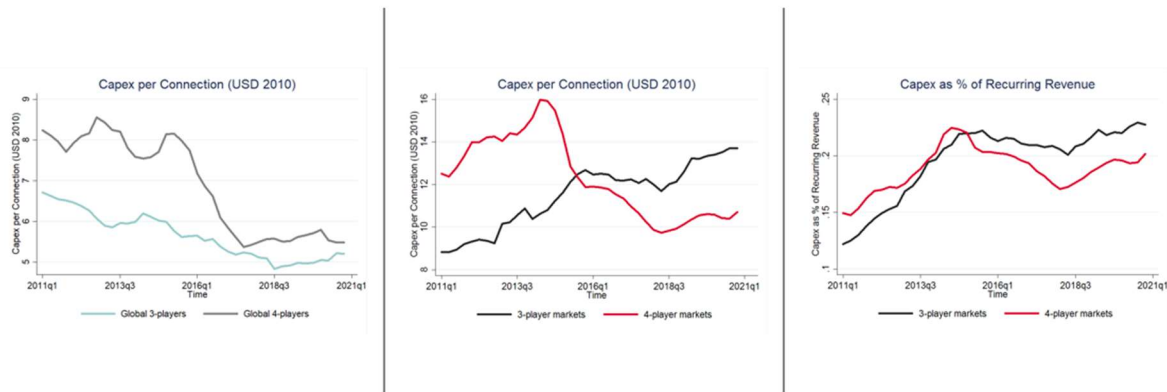
Figure 3: Share of 3G, 4G and 5G connections since technology launch



Source: GSMA Intelligence. Analysis shows the proportion of mobile connections that are accounted for by the new technology since their launch. 3G is assumed to start from 2002, 4G in 2010 and 5G in 2019. Gulf countries include the six countries in the Gulf Cooperation Council (GCC).

Differences in competitive conditions were also material between European markets in the 2011-2021 period, with relatively higher margins in those market with 3-players vs those with 4-players. In keeping with the theory of dynamic competition forces, higher market concentration and profit margins (and in particular the expectation of those continuing in the future) can be linked to greater investments. Trends on capital expenditure at an operator level is consistent with this theory from 2015 onwards, with operators in European three-player markets investing more per connection and as a proportion of revenues.

Figure 4: Capital expenditure



Source: GSMA Intelligence.

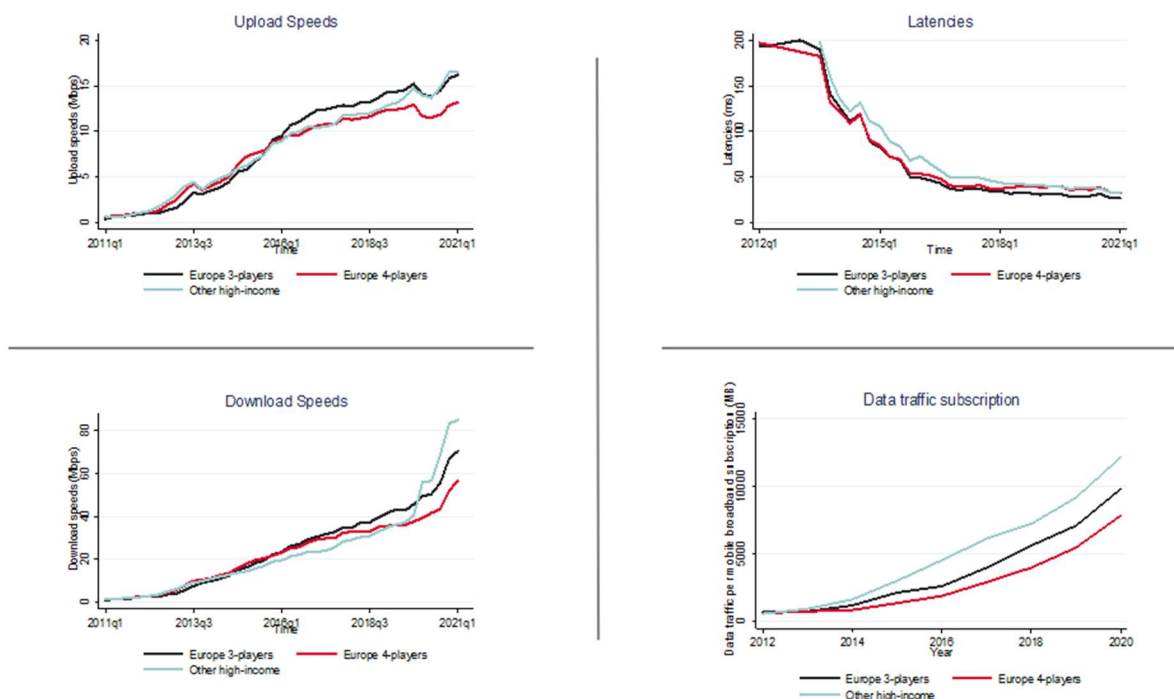
While investments per connection were larger in three- than in four-player markets in Europe after 2015, this is the opposite of what we observe globally. In the presence of large fixed costs, and everything else being equal, mobile markets with more players will experience a degree of duplication of infrastructure and therefore present greater aggregate investments overall. While this is the case for other regions, this is not observed in Europe. Despite the efficiencies expected in avoiding the duplication of fixed costs (i.e. lower capex), the analysis shows larger aggregate investments per subscriber in European three-player markets for most of the period. This may reflect the importance of dynamic competition, with greater capex efforts in delivering better quality, capacity and the roll-out of innovative network technologies and services, such as 5G.

Differences in dynamic competition conditions between markets can also impact the ability and incentives to differentiate products and services versus competitors in a market, for example by improving the quality of mobile service offerings. Higher download speeds allow consumers to access content more quickly and use data-intensive applications such as video. The figure shows that download speeds increased from below 5 Mbps in 2011 to more than 60 Mbps on average by 2021. At that point, three-players markets were outperforming four-players markets by almost 15 Mbps (or 25% higher). The difference between three-players and four-players markets is also apparent when assessing upload speeds, which were 24% higher in three-players markets than in four-players markets in 2021 (Figure 5). Higher upload speeds enable consumers to share more content and experience better performance of services such as video calls and online gaming, and hence they are as well an important feature of consumer welfare in mobile markets. This has particularly been the case since the outbreak of the Covid-19 pandemic, which drove large increases in upload traffic as a result of remote working, video calling and enterprise use (which is less asymmetric than consumer traffic).²⁵ Finally, latency (relevant for services that require short delays such as video calls or online gaming) also

²⁵ Figure 5 shows a notable short-term drop in upload speeds in 2020, which was due to the increase in network usage and congestion caused by the Covid-19 pandemic. For further analysis, see GSMA Intelligence, [How networks stayed the course as everyone stayed at home](#) (2021)

decreased dramatically from the beginning of the 4G era as consumers switched to 4G services. In 2021, latencies were 17% lower in three-player markets.

Figure 5: Network quality and data traffic



Source: Own analysis based on data sourced from ITU and Speedtest Intelligence by Ookla.

For the three network quality measures, we observe a distinct gap widening between three- and four-players markets in the second half of the 4G era, from late 2015 onwards. This gap may be partly linked to competition policy. The European Commission’s decision to impose the introduction of a new entrant as a pre-condition to approve a merger in Italy in 2016, and its subsequent decision to block a merger in the UK may have signalled to market players, intendedly or not, that further in-market consolidation in other markets would be very challenging or directly blocked²⁶. With dynamic competition conditions unlikely to change, this may have triggered an adjustment in capex decisions in 4-player markets. Coupled with strong mobile data traffic demand growth in most markets, network congestion impacted speeds and latencies in four-player markets from late 2015 onwards.

While dynamic competition forces are important, static competition effects (e.g. higher market power for individual players in more concentrated markets) could mean that higher profit margins and HHI values could be linked with higher retail prices for consumers. At the same time, in technological intensive sectors like mobile communications, dynamic competition forces can be the main driver of consumer price reductions, as new networks technologies are able to deliver services at a fraction of

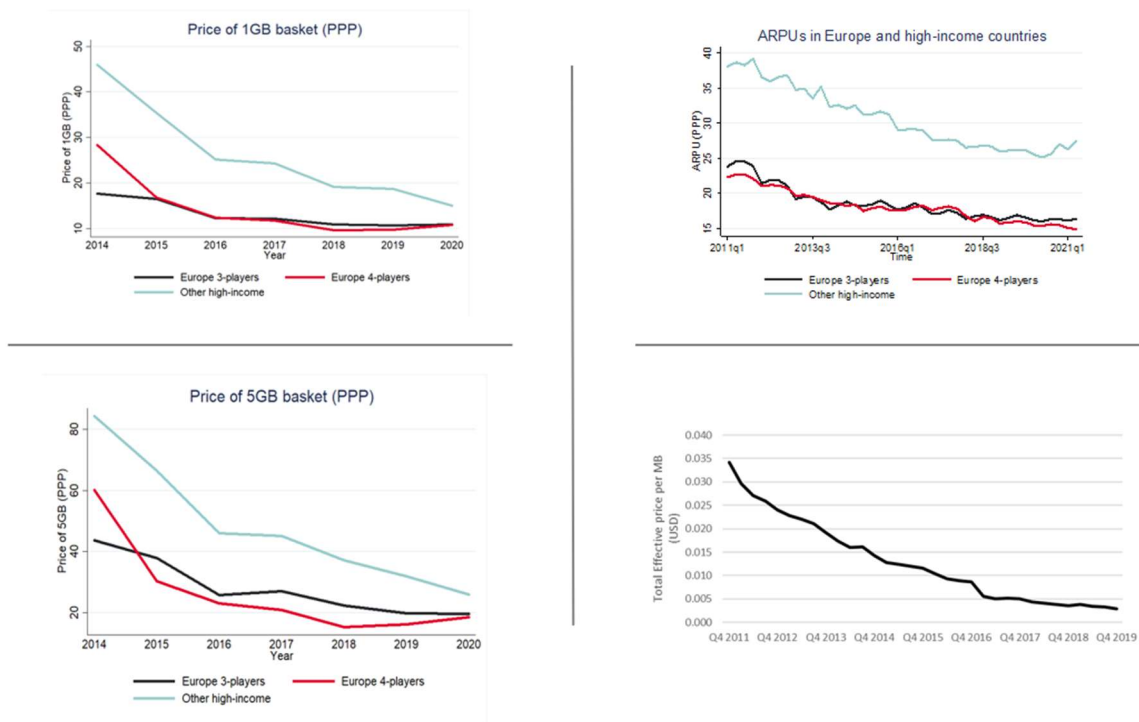
²⁶ See for example <https://www.ft.com/content/ebce00e6-28df-11e6-8b18-91555f2f4fde>.

the cost of previous generations.²⁷ In that case, higher market concentration and profit margins can be linked with greater ability and incentives to invest, innovate and roll-out new technologies and services. Consumer price effects therefore depend on which of the two effects dominates.

For the period 2011-2021 we analysed the average (recurring) revenue per user (ARPU) as a proxy for consumer prices. ARPUs trends suggest a clear price reduction in all markets, which underlines the importance of dynamic effects in driving price reductions per user in mobile markets. Across all markets, prices reduced by almost 50%. There is however no clear discernible difference between 3 and 4 player markets. If static effects were strong, one would expect to see significantly lower prices in 4-player markets, which is not the case.

We also considered the price of 1GB and 5GB consumption basket in the 2014-2020 period, where data was available at the country-level on an annual basis (see Annex 2 for further details). Prices did not significantly vary for the 1GB basket, while for 5GB the average price in 4-player markets was lower until 2020, when there was a convergence with 3-player markets. It is also notable that both ARPUs and basket-prices were significantly higher in other high-income countries compared to all European countries, regardless of whether they had 3 or 4 players, though the difference has reduced significantly over time.

Figure 6: Pricing trends



Source: Own analysis based on data sourced from GSMA Intelligence and Tarifica.

²⁷ For empirical evidence of this, see for example Nicolle et al (2019)

Overall, these trends suggest relatively weak conditions for dynamic competition in European four-player markets. Four-player markets were characterised by relatively low HHI and profit margins; experienced lower investments as a proportion of revenues and per connection; and did not improve service quality as much when compared to European three-player markets. At the same time, all markets experienced similar average consumer price reduction trends.

Economic theory fits well with these observed trends when dynamic competition effects are significantly stronger than static competition effects. In technology-intensive sectors, like European mobile markets during the period of the analysis, it is plausible that relatively more concentrated markets were able to generate larger incentives to invest, differentiate and improve products, and innovate, to the benefit of consumers.

While these observational descriptive statistics are suggestive, they do not show whether these trends are causally linked to each other. Without further analysis it could be argued that these trends occurred coincidentally at the same time or in countries that were intrinsically different, bearing no direct relation to each other. In order to establish robust correlations and causal effects, an empirical strategy in a multivariate analysis setting is required.

4. Methodology

Our data consists of a cross-sectional panel spanning 102 operators across 29 countries and 42 quarters between Q1 2011 and Q2 2021. Our main study variables are the market concentration measures HHI, the market share of the two largest operators ('C2')²⁸ and EBITDA margins²⁹. The latter does have some limitations, as it is based on accounting (rather than economic) profit and does not fully reflect the dynamic aspects of competition (especially in the technology sector).³⁰ For example, profits will partly depend on the stage of the technology cycle and the evolution of consumer demand, as well as broader macroeconomic trends and shocks. However, by focusing on changes in EBITDA margins over time (rather than absolute levels) over a full ten-year technology cycle, the metric is informative when considered alongside the other concentration measures.

We investigate the effects of market concentration and profitability on four performance measures that are linked to investment decisions in order to get a comprehensive view of the impact of competition dynamics across different aspects of the industry; investment; network quality; network coverage; and prices.

Our starting method is an OLS panel estimation with the following functional form:

$$(1) y_{i,c,t} = \alpha_c + \alpha_t + \sum_{k=1}^K \mu_k X_{i,c,t,k} + \rho Z_{c,t} + \varepsilon_{i,c,t}$$

Where:

$y_{i,c,t}$ is a performance or investment outcome of an operator i in country c in quarter t , e.g. download speeds, upload speeds, latencies, coverage or investment

α_c and α_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 topology) and year (e.g. technology upgrades, new handset releases)

X_{ict} is a set of control variables that predict changes in consumer outcomes. These vary for each consumer outcome but generally include income per capita, rural population share and spectrum holdings.

Z_{ct} is the market competition measure – either HHI, C2 or the number of operators in country c and quarter t . When using the EBITDA margin, we apply this at the operator level (Z_{ict}), as a measure of market power.

²⁸ HHI and C2 are calculated from operator market shares based on the number of mobile connections.

²⁹ We use EBITDA rather than EBIT because one of our main dependent variables is investment. Given that EBIT incorporates depreciation and amortisation, using it in our analysis would mean investment appearing as both a dependent and explanatory variable. Instead, EBITDA is more likely to impact investment – either a high EBITDA gives firms more ability to invest or it could reflect the existence of high market power, thereby reducing the incentive of the firm to invest.

³⁰ See for example OECD (2021) and Bork and Sidak (2013)

The above model is based at the operator level, in order to maximise the number of observations used and exploit the variation between operators within countries. We also estimate the models at a country-level, as follows:

$$(2) \quad y_{c,t} = \alpha_c + \alpha_t + \sum_{k=1}^K \mu_k X_{c,t,k} + \rho Z_{c,t} + \varepsilon_{i,c,t}$$

The variables are the same as the equation 1, but data is by country rather than operator. The market concentration measures are the same, with the exception of EBITDA, as we did not have data at the country-level.³¹

While equation 2 does not leverage the same degree of information or variation as equation 1, the two approaches allow us to test different theories. In principal, in a static sense one might expect that less concentrated markets (with more firms) would lead to less investment at the operator level and greater investment at the country level. This is because having more operators results in the duplication of infrastructure and fixed costs – meaning that country-level investment should increase. At the operator level, however, because firms will tend to be smaller in more concentrated markets (with smaller networks and/or a smaller customer base), then investment is likely to be lower per operator. However, in practice this may not be the case if we consider competition dynamics over time. If operators have more incentives to invest in less concentrated markets, then investment per operator could actually be higher (or lower in more concentrated markets). Alternatively, if firms have less ability to invest in less concentrated markets (for example due to lower returns and not having sufficient scale), then aggregate investment in the market could decrease (or increase in more concentrated markets). It is therefore relevant to consider the analysis at both the operator- and country-level as it allows us to directly test the strength of static and dynamic competition forces on investment levels.

In both analyses, we use country and time fixed effects to control for unobserved factors in individual countries (and over time within those countries). The remaining control variables are:

- GDP per capita: incomes capture the potential differences in demand for mobile services
- Rural population share: sparsely populated countries are harder to provide coverage to than more densely populated countries. In addition, providing capacity to rural areas is harder than for urban areas, due to greater requirements to invest in backhaul. This measure is preferred to population density because of the anomalies of uninhabited land. We note that the drawback of rural population share estimates (from Eurostat) is that each country carries its own definition of rural areas.
- Total country spectrum holdings : spectrum is a key part of the capacity available to operators. While we could include spectrum holdings at the operator level, one of the reasons why operators in more concentrated markets could potentially deliver better network quality or coverage is that spectrum resources are less dispersed between operators. As we want to

³¹ The data on EBITDA is sourced at the operator-level. In order to compile country-level estimates, we would require complete EBITDA data for each main operator in every country. Unfortunately, we did not have this information for all countries in all periods - therefore we estimate the model based on the available operator-level data.

capture this effect when assessing market structure, we have used total country spectrum holdings by technology (e.g. 4G or all depending on the outcome).

- Time of spectrum allocation : when analysing 4G coverage, we include variables to control for the time since spectrum was assigned in the country, as this will impact the roll-out of 4G networks.

Endogeneity concerns

It is well acknowledged in the industrial organisation literature³² that market concentration and profit levels can be affected by market outcomes as much as market outcomes are affected by market concentration and profit margins. In our case, given that the mobile industry is not a free-entry industry and the number of firms in the mobile market is determined to a significant extent by the availability of spectrum and the regulatory award of spectrum licenses, it is plausible that market structure may not be significantly determined by investment. Furthermore, in the period of analysis, there is evidence that antitrust decisions in two separate merger cases in 2016 (in Italy and the UK) were interpreted by European market players as a signal that further in-market consolidation in mobile markets would not be allowed.³³ We treat this change in regulatory expectations as an exogenous shock that impacted expected returns and investment decisions in less concentrated markets from that point onwards.

Nevertheless, to address any remaining potential concerns around two-way causality, we implement a model that use instruments in place of the market concentration variables. Our model for the first stage regression is:

$$(3a) \quad \tilde{Z}_{c,t} = \alpha_c + \alpha_t + \gamma H_{c,t} + \omega_{i,c,t}$$

From which fitted values of Z_{ct} are used in the second stage:

$$(3b) \quad y_{i,c,t} = \alpha_c + \alpha_t + \sum_{k=1}^K H_k X_{i,c,t,k} + \rho \tilde{Z}_{ct} + \varepsilon_{i,c,t}$$

Selecting instruments 'H' for first-stage model (3a) involves ensuring that any instrument is correlated with Z_{ct} but not with the error term from the second stage regression $\varepsilon_{i,c,t}$. That is, $H_{c,t}$ only impacts $y_{i,c,t}$ through its effect on Z_{ct} .

For market structure metrics HHI and C2, our preferred instrumental variables are the transformation of the share of spectrum holdings from the previous generation – i.e. when assessing 4G outcomes, this will be the share of 3G spectrum holdings.³⁴ As 3G spectrum was typically auctioned in the 2000s, it is unlikely to impact consumer outcomes during the 4G era, especially as 4G services were delivered over

³² See for example Evans et al (1993)

³³ See for example <https://www.ft.com/content/ebce00e6-28df-11e6-8b18-91555f2f4fde>

³⁴ We re-created an index of HHI using 3G spectrum shares instead of market shares and then employed a 2SLS approach using this as an instrument for HHI. It is in effect a replacement of (connections) market share with spectrum share when calculating these indices. For example, HHI, which is the sum of squared (connections) market shares was replaced with the sum of squared spectrum shares.

different spectrum bands. However, it is very likely to have formed the basis of market concentration going into the 4G era.

For profit margins, our preferred instrument is the amount of time since the operator launched its first network in the country. The more years since launch, the higher the margins that we would expect, since more time in the market may provide more efficient operations, scale, and knowledge, impacting both operators costs and its product differentiation or substitutability.

We also consider as an instrument for market structure the average HHI in the region, excluding the country of analysis.³⁵ This is because trends in market concentration in a given country may be impacted by concentration in neighboring countries – for example the approval of a merger in one country might lead operators in other countries to go ahead with a merger as well, especially as most European countries are members of the European Union and therefore subject to the ultimate approval of the same regulatory body: the European Commission. Alternatively, growing levels of concentration in some markets could lead to a reduction in concentration in others, if there is a concern about the former. Likewise, the successful entry of an operator in a market might also lead to entry in other countries (or unsuccessful entry in one market could deter entry in others). Given that many operators are active in multiple European markets, a successful strategy that increases market share in one country could also be replicated in other markets. The use of such spatial instruments is common in the empirical economics literature, though they have also been questioned because in many instances there are likely to be violations of the exclusion restriction³⁶. In this case, we need to assume two things: (i) concentration in country *j* does not impact outcomes in country *i*, and: (ii) the outcomes being considered in country *j* (e.g. investment and network quality) do not impact outcomes in country *i*.³⁷ It is possible that operator investment or prices in one country could be used in its decision to set prices or investment in another (or that decisions in one country are influenced by market trends in another). On the other hand, given the different environment of markets across Europe - in terms of size, geography and demand - it is not clear that a strong link would exist, particularly as the analysis is focused on one technology cycle. Given the potential caveats, we use regional HHI in combination with other instruments.

We also considered as an alternative instrument the level of competition in the fixed broadband sector, based on data sourced from the ITU'S ICT Regulatory Tracker.³⁸ The latter is a composite index defined by the ITU designed to facilitate benchmarking and identification of trends in ICT legal and regulatory frameworks. It includes indicators that measure the level of competition in fixed broadband (e.g. DSL, cable) as well as the status of the main fixed line operator (public, partially privatized, fully private etc). These factors reflect how enabling a country's overall telecoms framework is, which could impact concentration and market structure in the mobile sector, but they are unlikely to directly impact mobile market outcomes, such as investment or network quality. The limitation around this data is that the

³⁵ For example, the 'regional HHI' for France would be the average HHI across Europe excluding France.

³⁶ See for example Betz et al (2018)

³⁷ A third potential assumption is that one has to assume that there are no other omitted factors that are potentially impacting concentration in both country *i* and *j*.

³⁸ See <https://gen5.digital/>

metrics are captured using binary or categorical variables and so do not exhibit large variation across European countries in the 2011-2021 period. We therefore also only use it in combination with other instruments.

Another method commonly used to address the endogeneity of one or more regressors is to implement a dynamic panel data model. 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). The benefit of this approach is that a dynamic model might better reflect the multi-year investment plans of operators, as noted in Ofcom (2020), which applied such a model. In particular, past investment is likely to be a relevant driver of existing investment and therefore potentially coverage and network quality.

While a dynamic model approach has some attractions, it also has drawbacks. First, it requires a suitable identification of the model, including the number of relevant lags as well as the number and type of lags (levels or differences) to use as internal instruments. Having too many lags in the model can bias the results, leading to overfitting and weakening the diagnostic tests (the Hansen and Sargan tests). This often makes it difficult to reach strong conclusions as results can be very sensitive to these choices³⁹. Second, a dynamic model may better reflect the investment cycle over time but it does not address the potential endogeneity of market structure. One possibility is to use another internal instrument for the endogenous variable – in this case, the lag of HHI/C2/margins as an instrument for current market concentration/profit (this approach was implemented in Ofcom (2020)). However, this strategy relies on the assumption that historic market concentration has no impact on current investment or consumer outcomes, i.e. it assumes endogeneity does not work dynamically, even though the rest of the model does. This is unlikely to be plausible.

While noting these caveats, in addition to estimating models 1 and 2, as well as an instrumental variable approach, we also estimate a dynamic panel model as an additional robustness check, as follows:

$$(4) \quad y_{i,c,t} = \alpha_c + \alpha_t + \sum_{l=1}^n \phi_l y_{i,c,t-l} + \sum_{k=1}^K \mu_k X_{i,c,t,k} + \rho Z_{c,t} + \varepsilon_{i,c,t}$$

Where there are ‘n’ number of investment lags. In order to address the endogeneity introduced by including the lagged dependent variable, we implement the Arellano Bond estimator.⁴⁰ This model is used to check whether our main results for investment are robust to including past investment levels in the model.

³⁹ For further discussion, see Roodman (2009a)

⁴⁰ See Arellano and Bond (1991)

5. Results

Investment

Table 1 presents the summary results of regressions for investment per operator. Country fixed effects regressions (1), (2) and (3) show that more concentrated markets (measured with HHI and C2 indices) and higher profitability (measured with EBITDA margins) are linked to higher investment levels per operator. Regressions (4) to (9) present the results when we explicitly address the potential endogeneity bias that could arise if investment today drove market structure or margins in the long term.⁴¹ Based on the IV regressions, the results are consistent, showing a positive and statistically significant link between concentration/profitability and investment per operator. The diagnostics of the first stage regressions are presented in the Annex and they suggest that our selected instruments are valid for C2, HHI and EBITDA margins respectively.

Table 1: Results for log investment per operator (OLS and IV)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	OLS-FE	OLS-FE	OLS-FE	IV-FE	IV-FE	IV-FE	IV-FE	IV-FE	IV-FE
HHI	0.0026*** (0.0009)			0.00120** (0.000474)			0.00108* (0.000618)		
HHI squared	-0.0000** (0.0000)								
C2		0.1977*** (0.0547)			0.0666*** (0.0222)			0.0707 -0.0453	
C2 squared		-0.0013*** (0.0004)							
EBITDA			0.0184*** (0.0024)			0.0908** (0.0372)			0.0904** (0.0371)
EBITDA squared			-0.0000*** (0.0000)						
Instruments		N/A		Combination (see note a)			Single (see note b)		
Number of observations	2,229	2,229	2,143	2,229	2,229	2,143	2,229	2,229	2,143
R ²	0.81	0.81	0.83	N/A	N/A	N/A	N/A	N/A	N/A

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

Country-clustered standard errors in parentheses

Includes country and year fixed effects, as well as the control variables set out in Section 4.

(a) Combination of instruments for HHI and C2 includes concentration of 3G spectrum holdings, regional HHI and fixed broadband competition. For EBITDA, it includes time since network launch and fixed broadband competition

(b) Single instrument for HHI and C2 is the concentration of 3G spectrum holdings. For EBITDA, it includes time since network launch.

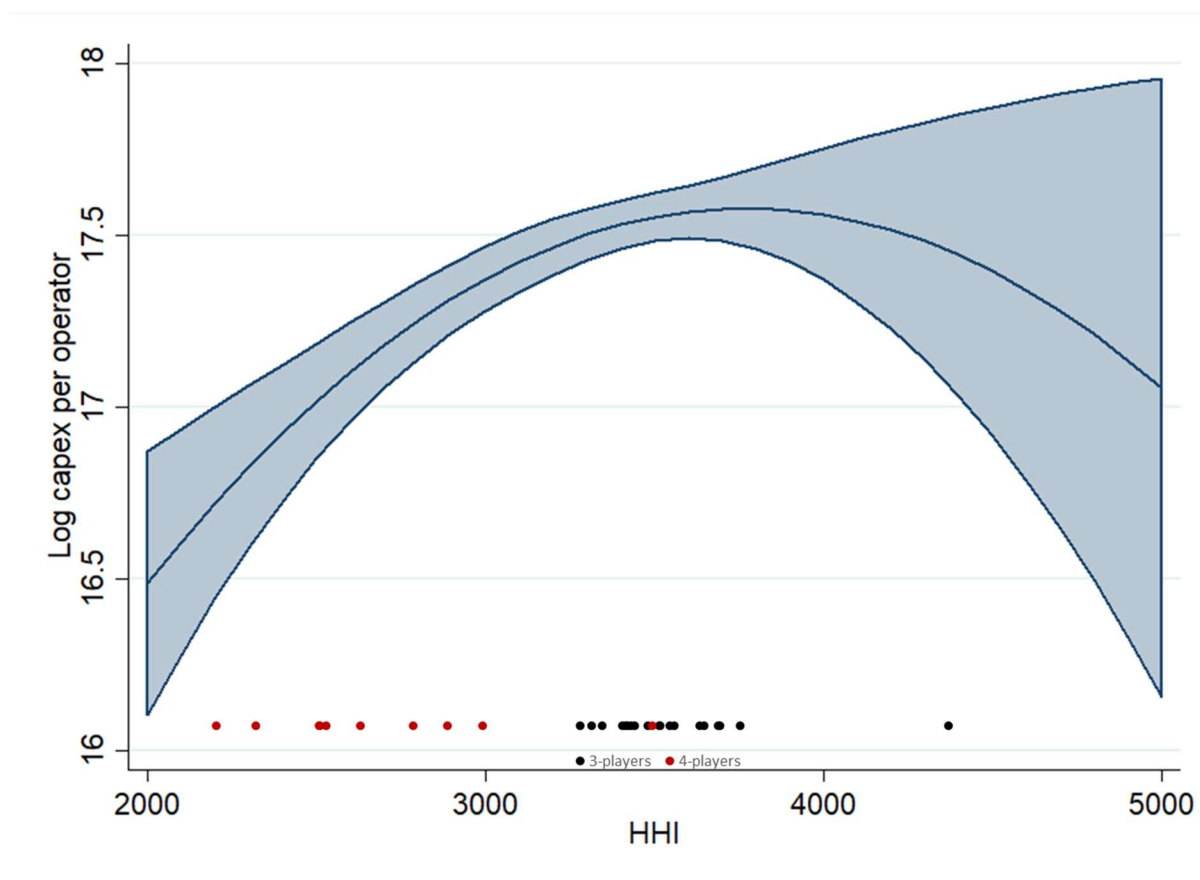
There is also evidence to suggest that the relationship is non-linear, as the included square term of C2, HHI and EBITDA margins has a negative and statistically significant coefficient, supporting the “U-shaped” investment and competition relationship that is suggested by economic theory and has also been found in other studies⁴². Figure 7 below shows the predicted values of HHI that would maximize investment levels. Increasing HHI drives higher investment up to an HHI of between 3600-3800. Plotting the values of these metrics against the actual HHI values in different European markets indicates that in all 4-player markets (and many 3-player markets) concentration is below the levels that would optimize investments. For example, based on the average HHI at the end of 2021 in 4-player markets

⁴¹ The IV regressions do not include a square term, as we only instrument the main concentration or profitability metric of interest.

⁴² See for example Hounghon & Jeanjean, 2017 and 2018; Abate, Castells & Pedros, 2018.

(around 2700), the analysis suggests that investment per operator is around 33% less than the optimal level that would be achieved with greater market concentration.

Figure 7: Inverted-U for capex and HHI



Note: Analysis is based on fixed effects OLS regression results presented in column (1) in table 1.

These econometric results are also consistent against a range of alternative checks. When regressed against capex per connection instead of capex per operator as the main dependent variable, the results hold. They also hold when we use the number of operators as a measure of market concentration (see Annex 3).

In additional specifications, presented in Annex 3, we further explore the potential variability of these effects when operators are in a network sharing agreement and in the aftermath of either market entry or exit. The overall conclusion is that even in the presence of network sharing, operators invest more in more concentrated markets. With regard to new entry or exit, there is some evidence that the effects of greater returns are strengthened following a market exit. The results for the two market concentration measures indicate that at least in the 2011-2021 period, there was no significant difference in the effect of concentration post market entry or exit.

We also tested the robustness of the results to the inclusion of past investments as lagged dependent variables. Since mobile market players make multi-year investment plans, it can be argued that investment decisions will be linked to investments made in the recent past. We therefore estimated an

alternative specification where investment per operator depends on the same set of controls as previously, but also on lagged values of investment. Estimating this model with fixed effects could give rise to dynamic panel data bias (Nickell, 1981), although it should be noted that if T is large compared to N, which is the case with our panel, dynamic panel bias becomes insignificant (Roodman, 2009a). Nevertheless, we estimate the dynamic panel data model using the Arellano-Bond GMM estimator (Arellano and Bond, 1991). One disadvantage of this family of estimators is that they are complex and can easily generate invalid results. For example, the number of instruments produced will be quadratic in T (Roodman, 2009b). Instrument proliferation can in turn overfit endogenous variables, making the results invalid.

We focus on a difference GMM estimator. This allows us to avoid making additional assumptions about the required structure and correlations of differenced variables and the error terms, which would be required with a system GMM estimator, while at the same time keeping the number of instruments needed at a more reasonable number. Table 2 presents the results. Regression (1) presents the findings with an OLS fixed effects estimator, but we focus on the GMM results: regression (2) includes one lag of investment four quarters before t, which we find to produce the best fit to the dataset, but we test for robustness to other lag structures, for example in (3)⁴³. We also extensively test the robustness of the results to limiting the number of instruments in (4) and (5)⁴⁴, as including too many lags as instruments can result in model misspecification and overfitting. The results consistently show that when taking into account lags of investment, the impact of market structure on capex per operator remains with the same sign and statistically significant. The diagnostic tests are as expected, with the Arellano–Bond autocorrelation test not rejecting the null hypothesis of no second order autocorrelation, and the Hansen test null hypothesis of exogenous instruments not being rejected either.

⁴³ In the absence of any theory that justifies a greater number of investment lags, we restrict them to a limited number. We find clear signs of multicollinearity arising when using two or more lags, with controls changing values and coefficients becoming unstable and with very large standard errors.

⁴⁴ This is achieved by collapsing instruments by taking averages of lagged values and limiting the number of lags used.

Table 2: Results for log investment per operator (dynamic panel models)

	(1)	(2)	(3)	(4)	(5)
Capex (t-4)	0.3428*** (0.0200)	0.5317*** (0.1493)	0.3810*** (0.1384)	0.5721*** (0.1699)	0.3530 (0.2871)
capex (t-6)			-0.2730** (0.1333)		
HHI	0.0003*** (0.0001)	0.0006** (0.0003)	0.0006** (0.0003)	0.0009*** (0.0003)	0.0013* (0.0007)
Instruments	0	74	74	39	29
AR (1)	N/A	-4.63***	-4.84***	-4.39***	-4.88***
AR (2)	N/A	0.56	0.37	0.98	1.44
Hansen test	N/A	53.37	48.02	28.23	24.44
Groups	78	76	75	76	76
Observations	2171	2082	2074	2082	2082

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

Country-clustered standard errors in parentheses

Includes country and year fixed effects

Overall, the results provide support to the hypothesis that trends observed in competition and investment aggregates (see section 3) can be at least partly explained by dynamic competition effects: the link between low concentration and profit margins and reduced investments is statistically significant and robust to all robustness checks, including the use of instrumental variables and dynamic panel data models.

Finally, when we estimate the model with aggregate investments at country level as our dependent variable, we find that these relationships do not hold and that changes in concentration do not have a significant impact on total investment. This is also consistent with much of the existing literature and it highlights the importance of looking at investment at both the operator- and country-level. The findings suggest that greater levels of concentration enhance dynamic competition by giving operators the means and incentives to invest more. At the country-level, this compensates for the reduction in fixed investments that might arise from having more concentrated markets. If this is passed onto consumers in the form of better networks and/or improved innovation, this would mean that investments in more concentrated markets are welfare-enhancing.

Table 3: Results for log investment per country (OLS and IV)

	(1)	(2)	(3)	(4)	(5)	(6)
	OLS-FE	OLS-FE	IV-FE	IV-FE	IV-FE	IV-FE
HHI	0.0007 (0.0008)		0.000271 (0.000276)		0.0000 (0.0001)	
HHI squared	-0.0000 (0.0000)					
C2		0.0726 (0.0603)		0.0190 (0.0172)		-0.000496 (0.00754)
C2 squared		-0.0005 (0.0004)				
Instruments	N/A		Combination (see note a)		Single (see note b)	
Number of observations	1,126	1,126	1,126	1,126	1,126	1,126
R ²	0.97	0.97	N/A	N/A	N/A	N/A

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

Country-clustered standard errors in parentheses

Includes country and year fixed effects, as well as the control variables set out in Section 4.

(a) Combination of instruments for HHI and C2 includes concentration of 3G spectrum holdings, regional HHI and fixed broadband competition.

(b) Single instrument for HHI and C2 is the concentration of 3G spectrum holdings.

Network quality

While investment can be a useful proxy for operator focus on quality, product differentiation and innovation, it is ultimately an input that impacts features that are important to consumer welfare. Our hypothesis is that competition dynamics can impact not just the amount of financial investment but also the efficiency per unit of investment, especially in the presence of large fixed and common costs and economies of scale and scope.

Table 4 presents the regression results of the impacts of competition dynamics on download speeds. Regressions (1), (2) and (3) present the results for the whole sample, while regressions (4), (5) and (6) focus on the period from 2015 onwards, where we identify a structural break in the dataset, driven by the emergence of network congestion from that point onwards (which can lead to lower speeds and higher latencies).⁴⁵ Furthermore, as discussed in Section 4, there is also evidence that antitrust decisions in two separate merger cases (in Italy and the UK) around that time were interpreted by European market players as a signal that further in-market consolidation in mobile markets would not be allowed. This may have triggered a downwards revision of expected returns and investment decisions – which could explain the emergence of network congestion in those markets.

In all cases, we find positive coefficients, linking an increase in market concentration or profit margins with an increase in download speeds. The effects are not statistically significant in the first part of the

⁴⁵ Results demonstrating the structural break are presented in Annex 3.

sample but become statistically significant in the period when network congestion starts to emerge. In Annex 3, we present the results when using an IV strategy. They remain positive and, in the case of EBITDA and HHI, statistically significant.

Additionally, we find a similarly positive link between competition dynamics and other measures of network quality (upload speeds and latency), albeit with lower statistical significance level in some specifications (see Annex 3). When we consider the impact of competition on 4G coverage, there is some evidence from the OLS regression analysis that higher market concentration accelerated 4G roll-out (see Annex 3).

Table 4: Results for download speeds (OLS)

	(1)	(2)	(3)	(4)	(5)	(6)
HHI	0.0178 (0.0198)			0.0700** (0.0293)		
HHI squared	-0.0000 (0.0000)			-0.0000** (0.0000)		
C2		0.4680 (1.5942)			4.3818** (2.0747)	
C2 squared		-0.0021 (0.0113)			-0.0296* (0.0154)	
EBITDA			0.0551 (0.0364)			0.1602*** (0.0503)
EBITDA squared			-0.0000 (0.0000)			0.0009** (0.0004)
Period of analysis		2011-2021		2015-2021		
Number of observations	3,755	3,755	2,433	2,320	2,320	1,376
R ²	0.76	0.76	0.82	0.59	0.59	0.72

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

Country-clustered standard errors in parentheses

Includes country and year fixed effects, as well as the control variables set out in Section 4.

Pricing

Finally, Table 5 presents the results of regressing C2 and HHI on ARPUs as a measure of consumer prices at the operator level⁴⁶ as well as 1GB and 5GB pricing baskets at the country level. None of the results suggest a statistically significant relationship between market structure and ARPU on mobile prices. We find similar results when using an IV specification (see Annex 3).

⁴⁶ We do not include EBITDA because both the dependent and independent variable of interest incorporate operator revenues in their calculations.

Table 5: Results for log ARPU and 1GB and 5GB pricing baskets (OLS)

	(1)	(2)	(3)	(4)	(5)	(6)
	ARPU-OLS	ARPU-OLS	1GB-OLS	1GB-OLS	5GB-OLS	5GB-OLS
HHI	-0.0005 (0.0004)		-0.0718 (0.0849)		-0.1983 (0.1886)	
HHI squared	0.0000 (0.0000)		0.0000 (0.0000)		0.0000 (0.0000)	
C2		-0.0144 (0.0297)		-7.4916 (6.6878)		-20.0116 (14.9670)
C2 squared		0.0001 (0.0002)		0.0428 (0.0422)		0.1215 (0.0966)
Number of observations	3,668	3,668	811	811	783	783
R ²	0.87	0.87	0.58	0.59	0.56	0.55

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

Country-clustered standard errors in parentheses

Includes country and year fixed effects, as well as the control variables set out in Section 4.

6. Conclusions

Both economic theory and the empirical literature have highlighted the important balance that needs to be considered between competition and investment. In mobile markets, this means that on the one hand, networks are characterised by large fixed and common costs, which means larger players with greater scale may drive more efficient investments. Furthermore, it is possible that in more concentrated mobile markets, firms may have a greater incentive to increase investment (as well as greater ability) because of the potential for higher returns. On the other hand, as market concentration decreases, it can drive greater competition between firms. This can create an incentive to invest more in better quality networks and/or new products and services, as a way of differentiating the firm from other competitors and thereby winning and retaining customers.

In this paper we investigate how these competition dynamics in Europe impacted investment and mobile network performance during the 2011-2021 period, a period that saw the roll-out of 4G networks, as well as the emergence of 5G. When compared to international benchmarks and Europe's three-player markets, European four-player markets were characterised by low concentration levels and profit margins. From 2015 onwards, four-player markets in Europe also experienced lower investments as a proportion of revenues and per connection; and did not improve service quality as much (download, upload, latencies), when compared to European three-player markets.

The results of the econometric analysis indicate that these trends can be partly explained by dynamic competition effects: the link between low concentration and profit margins and reduced investments per operator in Europe in this period is statistically significant and robust to a range of methodologies and checks. The evidence in this report indicates that market dynamics in many countries in Europe, especially in four-player markets, did not generate the optimal conditions that maximise investment levels. Economic theory fits well these results when dynamic competition effects are significantly stronger than static competition effects.

These results highlight the relative strength of dynamic over static competitive effects in a technology intensive sector like European mobile communications, where relatively more concentrated markets can generate large incentives to invest, differentiate and improve products, and innovate, to the benefit of consumers. In mobile markets, dynamic competition can be linked in particular to the ability and capacity to carry out investments that bring forward innovation (for example 5G, which can reduce unit costs and deliver new services) or product differentiation (better quality and services for consumers).

Improving dynamic competition conditions such as scale and incentives to obtain a return on investment would likely result in greater investments – and better services for consumers. European policymakers should therefore carefully consider the full range of policy levers that can generate the market outcomes desired in terms of investments, quality and prices. This includes a balanced consideration of the positive effects of mergers on dynamic competition incentives and investments. For example, regulatory remedies that artificially create entry do not necessarily strengthen the dynamic competition

conditions that the evidence shows are needed to enhance welfare. Competition policy can cause significant efficiency losses by not giving the appropriate weight to the long-term effects of investments and innovation on consumer welfare. European policymakers should therefore re-evaluate its substantive approach to competition policy, acknowledging the crucial role of investments in delivering consumer welfare and strengthening Europe's competitiveness in global markets.

Annex 1: Literature summary

Figure A1: Summary of assumed outcomes under *higher* market concentration

Study	Investment (operator)	Investment (country)	Quality and Innovation	Price	Scope
Bourreau and Jullien (2017)	NA	Higher	NA	Higher	Theoretical
Elliott et al (2021)	NA	Ambiguous	Ambiguous	Ambiguous	Theoretical
Federico, Langus, Valetti (2018)	NA	Ambiguous	Ambiguous	Higher	Theoretical
Jullien and Lefouili (2018)	NA	Ambiguous	Ambiguous	NA	Theoretical
Motta, Tarantino, 2021	NA	Lower	NA	Higher	Theoretical
Affeldt and Nitsche, 2014	NA	NA	NA	No effect, or possibly lower (unit price)	Europe, 2003-2012
Aguzzoni et al, 2018	NA	NA	NA	Higher for Netherlands No effect, or possibly lower for Austria (basket price)	Netherlands, 2007 merger Austria, 2006 merger
BEREC, 2018	NA	NA	NA	Higher in the short-term, no effect or inconclusive in long-term (basket price)	Austria, 2013 merger Ireland, 2014 merger Germany, 2014 merger
Bourreau et al, 2021	NA	NA	NA	Greater product variety and lower prices	France entry, 2011-14
Csorba and Papai (2015)	NA	NA	NA	Higher or no effect, depending on existing operators and entrants (basket price)	27 European countries, 2003-2010
Frontier Economics (2015)	NA	No effect	NA	No effect (unit price)	Europe, 2000-2014
Genakos, Valletti, Verboven (2018)	Higher per operator	Inconclusive at market level	NA	Higher (basket price)	OECD countries, 2002-2014

GSMA (2017)	NA	NA	Higher	NA	Austria, 2013 Merger
GSMA (2018)	"Inverted-U" at operator level	NA	Higher	NA	Central America, 2013-2016
GSMA (2020)	"Inverted-U" at operator level	Inconclusive at market level	Higher	No effect (ARPU)	29 European countries, 2011-2018
Houngbonon (2015)	NA	NA	NA	Lower (unit price per Gigabyte)	France, 2012 entry Austria, 2013 merger
Houngbonon and Jeanjean (2016)	"Inverted-U" at operator level	NA	NA	NA	110 operators, 2005 - 2012
Houngbonon and Jeanjean (2019)	Inverted-U (maximised with 3 symmetric operators, reduces in 3-to-2 merger)	NA	NA	Lower price per MB Higher price per user	18 European markets, 2007-2015
HSBC (2015)		NA	NA	Lower (unit price)	Austria, 2013 merger
HSBC (2015)	"Inverted-U" at operator level	NA	NA		66 markets, 2003 - 2013
Ofcom (2020)	NA	Lower	No direct effect	NA	Europe, 2000-2018
Nicolle et al (2019)	NA	NA	NA	Lower (quality adjusted price)	France entry, 2011-14
RTR (2016)	NA	NA	NA	Higher (basket price)	Austria, 2013 merger
WIK (2015)	NA	No effect	NA	NA	12 European and non-EU countries, 2005-2013

Annex 2: Data and metrics

This study considers data for 104 operators in the period Q1 2011 to Q2 2021, which covers the '4G era' in Europe. The data includes 29 European countries – 26 out of the 27 members of the European Union⁴⁷ along with the United Kingdom, Norway and Switzerland.

Figure A1: Scope of operators and countries, Q2 2011 to Q2 2021

Country	Number of operators	Country	Number of operators
Austria	4 -> 3	Lithuania	3
Belgium	3	Luxembourg	3
Bulgaria	3	Malta	3
Croatia	3	Netherlands	3 -> 4 -> 3**
Czech Republic	3	Norway	4 -> 3
Denmark	4	Poland	4
Estonia	3	Portugal	3
Finland	3	Romania	4
France	3 -> 4	Slovakia	3 -> 4
Germany	4 -> 3	Slovenia	4
Greece	3	Spain	4
Hungary	3	Sweden	4
Ireland	4 -> 3	Switzerland	3
Italy	4 -> 3 -> 4*	United Kingdom	4
Latvia	3		

* Following the merger in Italy between Hutchison and Wind in 2016, a new entrant (Iliad) entered the market in 2018.

** In the Netherlands, there was a new entrant (Tele2) in 2015 but it subsequently completed a merger with Deutsche Telecom in 2019.

Network Coverage

Data on network coverage is sourced from GSMA Intelligence and measures the proportion of the population resident in an area where 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.

Network Quality

We used data from Speedtest Intelligence® (sourced from Ookla®) to obtain network performance at an operator level. The Speedtest consumer-initiated testing platform allows mobile users to initiate a 'speed test' to measure network performance at any given time.⁴⁸ 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.⁴⁹ Each year,

⁴⁷ Cyprus was not used due to the existence of two practical mobile markets on the island

⁴⁸ <https://www.speedtest.net/apps/mobile>

⁴⁹ For further information on the Speedtest methodology, see <https://www.ookla.com/articles/how-ookla-ensures-accurate-reliable-data-2021>

Speedtest is used by 500 million unique users globally, and an average of 10 million consumer-initiated performance tests are run per day.

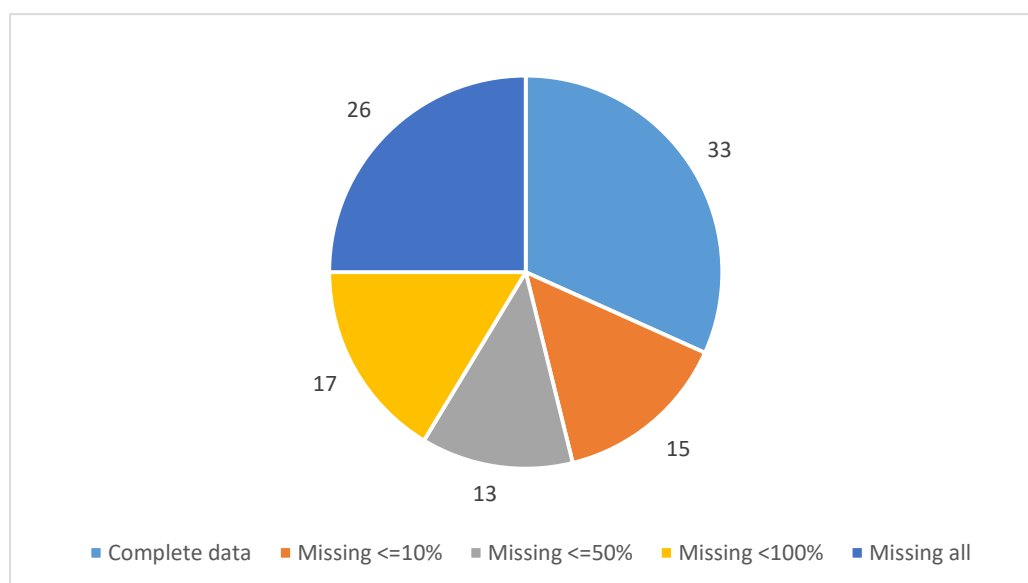
Using these test results, Ookla calculates the average network performance metric across all users in each quarter at both the country and operator level. In this study, we focussed on:

- Download speeds (higher speeds allow consumers to download content more quickly and use data-intensive applications and content, such as video)
- Upload speeds (higher speeds enable consumers to share more content and experience better performance of services such as online gaming)
- Latency (relevant for services that require short delays such as video calls, Voice over IP or online gaming)

Investment

We assess investment by measuring changes in capital expenditure. We use data from GSMA Intelligence on capital expenditure at an operator level. This is primarily sourced from operator-reported capex data, though it is more limited in availability than data on network quality and coverage (see Figure A4). During the 2011-2021 period, there are 33 operators (out of 104) that have complete data for every quarter (see Figure A2). For 61 of the operators in the sample, there is data for more than half of the quarters, while there is no data at all for 26 operators. When carrying out the analysis for capex, our primary analysis only includes operators for which there is capex data available – it therefore excludes the 26 operators without any data. Where capex data is available, we convert it to real prices (2010 USD prices) using the Consumer Price Index sourced from the World Bank. When using investment measures in our econometric analyses, we apply a logarithmic transformation.

Figure A2: Capex data availability for operators



Source: GSMA Intelligence

In order to generate capex at the country-level, given that data is not available for all operators, it is necessary to produce capex estimates for when the data is missing. For each of the 29 countries, there is at least one operator with reported capex data in the 2011-2021 period. GSMA Intelligence estimates the remaining missing data for each operator using a bottom-up model based on the estimated cost of a base station (which depends on the technology, i.e. 2G, G3, 4G or 5G), and by estimating the number of base stations needed given population density, operator coverage and take-up, and also taking account of the increased data usage over time. This provides a country-level metric for aggregate investment, which is used for the country-level analysis of investment.

Consumer pricing

In order to consider the impact of market structure on the full range of outcomes that are valued by consumers, it is relevant to look at the price of mobile services. However, there are a number of challenges in constructing a price measure that fulfils a representation of consumers' payments as well as one that is consistent over time. Figure A3 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 A3: Measures of mobile prices

Price metric	Description	Pros	Cons
Average revenue per user (ARPU)	Divide operator revenues by subscribers or connections	Relatively easy to source data and calculate.	Metric is affected by prices <i>and</i> usage. Does not measure effectively changes to tariffs and plans currently being offered by mobile operators. ARPU blends all of the customers and associated revenue and is therefore skewed by connections with low activity.
Basket-based pricing	Define a basket of mobile services (e.g. 1GB of data + 500 minutes per month) in order to assess differences in price across countries and time. Basket prices are typically generated by researching the lowest priced package for the basket specified in each time period.	Gives a better indication of what consumers actually pay for mobile services. Can fix baskets to ensure only price changes (and not quantity) 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-based pricing	Effective price per MB (or other unit such as minutes) which can be drawn from the cheapest basket on a per MB basis, or from average revenue per MB where revenues are disaggregated by operators.	Controls for changes in quantity consumed. Consistent with assessment of investment, which allows for greater capacity and usage of data.	Difficult to estimate as voice, SMS and data are bundled together.

For the period 2011-2021 and for the countries included in the study, the only metric that was available to us to perform pricing analysis at the operator level was average (recurring) revenue per user (ARPU). We therefore carry out our empirical analysis using this metric, converting it to real prices (2010 USD prices) using the Consumer Price Index sourced from the World Bank. However, given the shortcomings of ARPU as a measure of prices, the results should be treated with caution. We also carried out country-level analysis using a basket-based pricing approach. Using data sourced from Tarifica, for each country we considered the cheapest way in which consumers can purchase 1GB and 5GB of monthly data.⁵⁰ However, this should also be treated with some caveats as the data was only available at a country-level from 2014 on an annual basis

Market concentration measures

There are different of measures of market concentration that can be used to determine how a market is structured. We consider the following:

- Number of players: we use a 5% connections share threshold to count the number of major players in each market. Based on this threshold, during the 4G era Europe consisted of three- and four- major player markets.
- Herfindahl-Hirschman Index: the primary measure of market concentration with values between 0 and 10,000, increasing values suggesting a higher level of market concentration. The index is formed by summing the squares of individual operator market shares within each market.
- C2: this is the sum of market shares for the largest two operators in each country.
- EBITDA: we leverage operator-level EBITDA as a measure of profitability.

HHI and C2 are based on market shares (by connections), which were sourced from GSMA Intelligence.⁵¹ EBITDA data is also sourced from GSMA Intelligence, which gathers the information from operator-reported data. Within the sample of 104 operators, our data includes complete EBITDA data for 42 operators, while for 66 operators there is data in more than half of quarters considered in the study. There are 20 operators with no reported EBITDA data at all. Each country has at least one operator with reported data. The results are therefore subject to data limitations in terms of what is reported by operators, though the overall sample size is more than sufficient to consider an econometric analysis.

⁵⁰ For further details on the methodology, see GSMA [Mobile Connectivity Index Methodology](#)

⁵¹ <https://www.gsmainelligence.com/>

Figure A4: Summary statistics

Variable	Source	Observations	Mean	Standard Deviation	Minimum	Maximum
Average download speeds (Mbps)	Speedtest Intelligence, Ookla	3,868	24.49	20.17	0.19	159.16
Average upload speeds (Mbps)	Speedtest Intelligence, Ookla	3,868	8.26	5.74	0.08	29.54
Average latency (ms)	Speedtest Intelligence, Ookla	3,868	92.83	82.82	16.52	636.53
4G coverage (% of population)	GSMA Intelligence	4,036	65.57	39.58	0.00	100.00
Capex per connection (2010 USD)	GSMA Intelligence	2,321	3.64	4.48	0.00	63.08
ARPU (2010 USD)	GSMA Intelligence	3,829	19.52	10.03	1.86	65.11
Share of population in rural areas (%)	World Bank	3,842	26.45	12.65	1.92	47.12
GDP per capita (euros, chain linked volumes 2010)	Eurostat	4,024	7,142	4,635	1,100	21,770
Total spectrum holdings (MHz)	GSMA Intelligence	4,005	520	162	129	1,389
HHI	GSMA Intelligence	4,036	3,284	514	2,237	4,620
C2	GSMA Intelligence	4,036	72	9	53	91
EBITDA	GSMA Intelligence	2,546	28.16	14.12	-88.69	74.94

Annex 3: Further analysis and robustness checks

In this annex, we present the results of additional models. This is to check whether our findings are robust to alternative specifications and assumptions. We also present the results of our main models for upload speeds and latencies.

Investment

Table A1 presents the results of the OLS and IV models for the log of operator investment, normalized by the number of connections. The results are consistent with those presented in Section 5 for log investment per operator.

Table A1: Results for log investment per connection (OLS and IV)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	OLS-FE	OLS-FE	OLS-FE	IV-FE	IV-FE	IV-FE	IV-FE	IV-FE	IV-FE
HHI	0.0030*** (0.0009)			0.00122*** (0.000432)			0.00117* (0.000625)		
HHI squared	-0.0000** (0.0000)								
C2		0.2459*** (0.0527)			0.0659*** (0.0213)			0.0767* (0.0459)	
C2 squared		-0.0016*** (0.0004)							
EBITDA			0.0168*** (0.0023)			0.0765*** (0.0257)			0.0763*** (0.0257)
EBITDA squared			0.0000 (0.0000)						
Instruments		N/A		Combination (see note a)			Single (see note b)		
Number of observations	2,226	2,226	2,141	2,227	2,227	2,142	2,227	2,227	2,142
R ²	0.4719	0.4696	0.5175	N/A	N/A	N/A	N/A	N/A	N/A

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

Country-clustered standard errors in parentheses

Includes country and year fixed effects, as well as the control variables set out in Section 4.

(a) Combination of instruments for HHI and C2 includes concentration of 3G spectrum holdings, regional HHI and fixed broadband competition. For EBITDA, it includes time since network launch and fixed broadband competition

(b) Single instrument for HHI and C2 is the concentration of 3G spectrum holdings. For EBITDA, it includes time since network launch.

Impact of network sharing and market entry/exit

The impact of changes in competition may vary depending on the existing market structure. For example, it is possible that the entry of a new player has a larger impact on investment and network coverage or quality than the merger of two existing firms (or vice versa).⁵² In order to better understand this, we run the specification below:

$$y_{i,c,t} = \alpha_c + \alpha_t + \sum_{k=1}^K \mu_k X_{i,c,t,k} + \rho Z_{c,t} + \sigma Z_{c,t} * E_{c,t} + \tau Z_{c,t} * M_{c,t} + \varepsilon_{i,c,t}$$

⁵² This was seen for example in Ofcom (2020)

Where $E_{c,t}$ is a dummy variable that takes a value of 1 if there was a new entrant in country c within the previous 3 years of period t and $M_{c,t}$ is a dummy variable that takes a value of 1 if there was a merger in country c within the previous 3 years of period t . Both of the dummy variables are interacted with the measure of competition (HHI, C2, EBITDA), in order to determine whether the latter has a larger or smaller effect after there has been a merger or new entrant.

We also check whether our results are robust to the inclusion of network sharing effects. Given that network sharing has been shown to impact investment, operator returns and consumer outcomes such as network coverage and quality, it is possible that the impact of competition may differ depending on whether or the operator in a given country is part of a network sharing agreement. For example, if network sharing drives efficiencies in investment, it is possible that changes in market structure at the retail level have a greater impact if no network sharing is in place (or have less impact when there is network sharing). In order to check this, we run a variation of the equation above where, instead of interacting the competition metric with merger and entry events, we interact it with a dummy variable $N_{i,c,t}$ that takes value 1 if operator i in country c entered into a network sharing agreement within the previous 3 years of time t .

Tables A2 and A3 presents the results of the OLS models for investment per operator when we interact market concentration and profitability with a dummy variable for network sharing (Table A2) and the market entry or exit of an operator in the previous three years (Table A3). Table A2 shows that the main finding that higher concentration and profit increases investment holds when we control for network sharing. For operators in a network sharing agreement, the negative coefficients would indicate that their investment gains are less than those that are not sharing networks – however, only the C2 interaction is statistically significant at the 10% level.

Table A3 shows that when looking at the market concentration measures, there is no additional effect when following recent entry or exit events. For profitability, investment increases more for market exit than it decreases for market entry.

Table A2: Network share interactions for log investment per operator

	(1)	(2)	(3)
	OLS-FE	OLS-FE	OLS-FE
HHI	0.0028*** (0.0009)		
HHI * Network sharing	-0.0003 (0.0002)		
C2		0.2205*** (0.0532)	
C2 * Network sharing		-0.0246* (0.0126)	
EBITDA			0.0197*** (0.0022)
EBITDA * Network sharing			-0.0047 (0.0038)

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

Country-clustered standard errors in parentheses

Includes country and year fixed effects, as well as the control variables set out in Section 4.

Table A3: Market entry/exit interactions for investment per operator

	(1)	(2)	(3)
	OLS-FE	OLS-FE	OLS-FE
HHI	0.0027*** (0.0009)		
HHI * Entry	0.0000 (0.0000)		
HHI * Exit	-0.0000 (0.0000)		
C2		0.1962*** (0.0575)	
C2 * Entry		0.0001 (0.0007)	
C2 * Exit		0.0003 (0.0012)	
EBITDA			0.0178*** (0.0023)
EBITDA * Entry			-0.0018 (0.0012)
EBITDA * Exit			0.0056** (0.0021)

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

Country-clustered standard errors in parentheses

Includes country and year fixed effects, as well as the control variables set out in Section 4.

Structural break in network quality measures

The trend analysis presented in Section 3 showed a notable break in download speeds, upload speeds and latencies during the period of analysis. This may have been triggered by a change in regulatory expectations in regards to further in-market consolidation that reduced expected returns and investment decisions in less concentrated markets from that point onwards. Since this also occurred at a time when 4G adoption was significantly increasing, it may have meant operators had to manage network congestion. In order to check this statistically, we tested for the existence of a structural break in the data. Table A4 presents the results for download, upload speeds and latencies.⁵³ In all cases, the tests reject the null hypothesis of there being no structural break. The estimated break dates are 2014q4 for download speeds and latencies and 2015q1 for upload speeds. We therefore run our analysis using the full sample and a restricted sample from 2015 onwards.

Table A4: Structural break tests for network quality metrics

	Download speeds	Upload speeds	Latencies
Estimated break date	2014q4	2015q1	2014q4
Wald statistic p-value	0.0000	0.0000	0.0107
Average likelihood ratio p-value	0.0014	0.0001	0.0012

Supremum Wald and average likelihood ratio tests the null hypothesis of no structural break

Download Speeds

Table A5 presents the results of the IV strategy for download speeds when we consider the period from 2015 onwards. It shows that higher profit margins and concentration (when measured by HHI) drove faster download speeds, which is consistent with the OLS specification. The coefficients for C2 are also positive, but statistically insignificant at both the 5% and 10% level.

⁵³ This was implemented in Stata using the 'estat sbsingle' and 'estat sbknown' commands after regressing the relevant network quality metric on HHI.

Table A5: Results for download speeds from 2015 (IV)

	(1)	(2)	(3)	(4)	(5)	(6)
HHI	0.0137*			0.00514		
	(0.00728)			(0.00770)		
C2		0.532			0.356	
		(0.455)			(0.525)	
EBITDA			0.332**			0.327**
			(0.137)			(0.136)
Instruments	Combination (see note a)			Single (see note b)		
Number of observations	2,282	2,282	1,376	2,282	2,282	1,376

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

Country-clustered standard errors in parentheses

Includes country and year fixed effects, as well as the control variables set out in Section 4.

(a) Combination of instruments for HHI and C2 includes concentration of 3G spectrum holdings, regional HHI and fixed broadband competition. For EBITDA, it includes time since network launch and fixed broadband competition

(b) Single instrument for HHI and C2 is the concentration of 3G spectrum holdings. For EBITDA, it includes time since network launch.

Upload speeds and latencies

Tables A6 and A7 presents the results of the OLS models for upload speeds and latencies respectively. Overall, the results suggest higher levels of concentration and profitability are associated with greater upload speeds, though only the results for profitability are statistically significant from 2015. In terms of latencies, the results are mostly statistically insignificant and inconclusive (with positive coefficients for the full sample but negative coefficients for C2 and EBITDA from 2015).

Table A6: Results for upload speeds (OLS)

	(1)	(2)	(3)	(4)	(5)	(6)
HHI	0.0029 (0.0084)			0.0070 (0.0067)		
HHI squared	-0.0000 (0.0000)			-0.0000 (0.0000)		
C2		0.0470 (0.6798)			0.6497 (0.5276)	
C2 squared		-0.0001 (0.0046)			-0.0042 (0.0039)	
EBITDA			0.0069 (0.0056)			0.0265*** (0.0063)
EBITDA squared			-0.0000 (0.0000)			0.0001*** (0.0001)
Period of analysis		2011-2021			2015-2021	
Number of observations	3,755	3,755	2,433	2,320	2,320	1,376
R ²	0.7822	0.7822	0.8590	0.5418	0.5408	0.7498

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

Country-clustered standard errors in parentheses

Includes country and year fixed effects, as well as the control variables set out in Section 4.

Table A7: Results for latencies (OLS)

	(1)	(2)	(3)	(4)	(5)	(6)
HHI	0.1601* (0.0874)			0.0287 (0.0351)		
HHI squared	-0.0000* (0.0000)			-0.0000 (0.0000)		
C2		8.2395 (6.5769)			-0.1025 (2.5184)	
C2 squared		-0.0573 (0.0453)			0.0044 (0.0181)	
EBITDA			0.0283 (0.2057)			-0.1174 (0.0845)
EBITDA squared			-0.0001 (0.0002)			0.0005 (0.0003)
Period of analysis		2011-2021			2015-2021	
Number of observations	3,755	3,755	2,433	2,320	2,320	1,376
R ²	0.7931	0.7919	0.7820	0.5882	0.5888	0.6026

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

Country-clustered standard errors in parentheses

Includes country and year fixed effects, as well as the control variables set out in Section 4.

4G coverage

Table A8 presents the results for OLS analysis for 4G coverage. Regressions (1) to (3) show no statistically significant findings for the full sample. When we limit the analysis to the main period of roll-out, before operators had reached 90% coverage, we find evidence that higher levels of market concentration (HHI and C2) are associated with faster 4G network roll-out. These results are not statistically significant in the IV specification, as shown in Table A9.

Table A8: Results for 4G coverage (OLS)

	(1)	(2)	(3)	(4)	(5)	(6)
HHI	-0.0253 (0.0617)			0.1641** (0.0646)		
HHI squared	0.0000 (0.0000)			-0.0000** (0.0000)		
C2		-2.3712 (3.8680)			10.3431** (4.2990)	
C2 squared		0.0182 (0.0283)			-0.0757** (0.0316)	
EBITDA			0.0671 (0.1206)			0.1097 (0.1292)
EBITDA squared			-0.0001 (0.0001)			-0.0001 (0.0001)
Period of analysis	Coverage up to 99%			Coverage up to 90%		
Number of observations	2,131	2,131	1,402	1,205	1,205	847
R ²	0.7390	0.7387	0.7671	0.6337	0.6352	0.6644

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

Country-clustered standard errors in parentheses

Includes country and year fixed effects, as well as the control variables set out in Section 4.

Table A9: Results for 4G coverage (IV)

	(1)	(2)	(3)	(4)	(5)	(6)
HHI	0.00247 (0.00514)			0.00978 (0.00845)		
C2		0.164 (0.322)			0.606 (0.530)	
EBITDA			1.083** (0.494)			1.084** (0.494)
Instruments	Combination (see note a)			Single (see note b)		
Number of observations	1,205	1,205	847	1,205	1,205	847

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

Country-clustered standard errors in parentheses

Includes country and year fixed effects, as well as the control variables set out in Section 4.

(a) Combination of instruments for HHI and C2 includes concentration of 3G spectrum holdings, regional HHI and fixed broadband competition. For EBITDA, it includes time since network launch and fixed

(b) Single instrument for HHI and C2 is the concentration of 3G spectrum holdings. For EBITDA, it includes time since network launch.

Pricing

Table A10 shows the results of the IV analysis for ARPUs at the operator level and prices at the country-level for 1GB and 5GB baskets. All of the results are statistically insignificant, further suggesting that higher levels of market concentration did not drive higher (or lower) prices in Europe in the period of analysis.

Table A10: Results for pricing baskets

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	ARPU-IV	ARPU-IV	ARPU-IV	ARPU-IV	1GB-IV	1GB-IV	5GB-IV	5GB-IV
HHI	0.0000 (0.0001)		0.0000 (0.0003)		-0.0633 (0.0437)		-0.118 (0.0919)	
HHI squared								
C2		-0.00301 (0.00604)		-0.00959 (0.0194)		-4.071 (2.685)		-7.916 (5.544)
C2 squared								
Instruments	Combination (see note a)		Single (see note b)		Combination (see note a)		Combination (see note a)	
Number of observations	3,648	3,648	3,648	3,648	811	811	783	783
R ²	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

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

Country-clustered standard errors in parentheses

Includes country and year fixed effects, as well as the control variables set out in Section 4.

(a) Combination of instruments for HHI and C2 includes concentration of 3G spectrum holdings, regional HHI and fixed broadband competition.

(b) Single instrument for HHI and C2 is the concentration of 3G spectrum holdings.

Number of operators

Table A11 shows results from the OLS specifications where we use the number of operators as a measure for concentration – as countries only had 3 or 4 operators in the period of analysis, the dependent variable of interest is a dummy that takes a value of 1 if the country is a 3-player market. While this exhibits less variation than the other market concentration measures and does not reflect differences in competition *within* 3- and 4-player markets, the results are largely consistent in that they show that 3-player markets had higher investment per operator (with no difference at the country-level) and faster download speeds from 2015. The results for ARPU are positive and statistically significant, but for the pricing baskets they are negative and statistically insignificant.

Table A11: Results for consumer outcomes using number of operators

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Log capex per operator	Log capex per country	Download speeds	Download speeds (from 2015)	4G Coverage	ARPU	1 GB Basket	5GB Basket
3-player market	0.2667** (0.1017)	-0.0093 (0.0441)	0.0053 (2.6013)	8.6138*** (1.8205)	1.1669 (2.9804)	0.0690*** (0.0237)	-12.7296 (9.6062)	-30.8646 (21.0558)
Number of observations	2,229	1,126	3,755	2,320	2,131	3,668	811	783
R ²	0.8084	0.9713	0.7622	0.5899	0.7378	0.8687	0.5583	0.5376

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

Country-clustered standard errors in parentheses

Includes country and year fixed effects, as well as the control variables set out in Section 4.

(b) Single instrument for HHI and C2 is the concentration of 3G spectrum holdings. For EBITDA, it includes time since network launch.

Annex 4: First stage outputs for instrumental variable regressions

Table A12 presents the results and diagnostics of the first stage regressions on HHI, C2 and EBITDA. The majority of instruments are statistically significant and operate in the expected direction. More concentrated 3G spectrum shares are linked to a higher HHI in the 4G era and operators that have been active in a market for longer have a higher profitability. The presence of greater competition in the fixed broadband sector, which may reflect regulatory policies that promote more competition, is associated with lower HHI and C2. The Sanderson-Windmeijer statistics for weak identification suggest the instruments are valid, though we note that the first stage F-statistics are lower than the typically used threshold of 10 for strong instruments. This could be one of the reasons why some of the results in an IV setting lose statistical significance compared to the OLS analysis. Where we use a combination of instruments, we check the null hypothesis that the instruments are uncorrelated with the error term – these are not rejected, suggesting the instruments are valid.

Table A12: First stage OLS regressions for HHI, C2 and EBITDA

	(1) HHI	(2) HHI	(3) C2	(4) C2	(5) EBITDA	(6) EBITDA
3G spectrum share index	0.473* (0.269)	0.411* (0.247)	0.00722* (0.00435)	0.00602 (0.00398)		
Time since network launch					0.185* (0.0957)	0.185* (0.0957)
Regional HHI		-2.855*** (0.797)		-0.0457*** (0.0143)		
Fixed broadband competition		-339.4** (158.8)		-14.17** (5.971)		-4.844 (5.218)
Number of observations	2,229	2,229	2,229	2,229	2,143	2,143
Partial R ²	0.129	0.195	0.0857	0.182	0.0169	0.0170
First-stage F-test*	3.081	9.014	2.750	7.431	3.732	2.468
Weak identification p-value**	0.0906	0.000266	0.109	0.000881	0.0639	0.104
Overidentification p-value***	N/A	0.805	N/A	0.753	N/A	0.516
Endogeneity p-value***	0.15	0.00	0.089	0.00	0.01	0.01

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

Country-clustered standard errors in parentheses

Includes country and year fixed effects, as well as the control variables set out in Section 4.

* Reports the F statistic for joint significance and the associated p-value

** Reports the p-value of the Sanderson-Windmeijer statistic. Null hypothesis is that the model is weakly identified

*** 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

*** Reports the p-value of the endogeneity test (C statistic). Null hypothesis is that the endogenous regressors are in fact exogenous.

Annex 5: References

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