Is there a level of competition intensity that maximizes investment in the mobile telecommunications industry?[*]

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Preliminary version, comments are welcome

Abstract

This paper empirically assesses the causal impact of competition on investment in new technologies using firm level data from the mobile telecommunications industry. It finds an inverted-U relationship between the intensity of competition and investment. The investment maximizing intensity of competition stands at 63 percent plus or minus 6 percentage points at the 5% confidence level. This means that the maximal level of investment is reached when the operating profit represents 37 percent of total revenue. This result is robust across regions of World, notably Asia-Pacific, Western Europe and Africa. It is also robust to investment in the network quality. Moreover, it finds that the threat of entry reduces the incentive to invest in the mobile network and can explain 4 percentage points of the investment maximizing intensity of competition. Finally, this paper also shows that unlike the extensive investment, intensive investment; that is the ratio of the extensive investment over revenue, has a U-shaped relationship with the intensity of competition. It provides a simple theoretical model to show that these results can partly be explained by the size of innovation in the mobile telecommunications industry. The larger the size of innovation, the lower is the investment maximizing intensity of competition.

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1 Introduction

The relationship between competition and investment is the topic of a large economic literature. Although the debate has been lively for many decades, no clear-cut conclusion has been reached so far. There are mainly two opposite views about the direction of the relation. The Schumpeterian view highlights that large firms in low concentrated markets are more likely to invest, and the school of Harvard's view highlights the virtues of competition that stimulates investment to escape competition. One of the significant contributions to this debate is the findings by Aghion, Bloom, Blundell, Griffith, and Howitt (2005) of an inverted-U relationship between competition and investment in R&D. While these findings raise a caution about the relevance of perfect competition as a policy objective, they do not identify the level of competition which maximizes investment, as this level may depend on each industry.

The goal of this paper is to assess empirically whether there is a level of competition intensity that maximizes investment in infrastructures and network quality within the mobile telecommunications industry. It takes advantage of the availability of firm level data on mobile network operators worldwide to identify the causal impact of the intensity of competition on investment. The intensity of competition is measured at the firm level as 1-Lerner index and investment is the quarterly expenditures in tangible and durable assets. The identification strategy stems from the cross-firms and cross-country differences in the intensity of competition due to the date of entry into the market and the number of frequency bands released by regulators.

It turns out that there is an inverted-U relationship between competition intensity and investment. That is, investment is maximal for an intermediate level of competition intensity between monopoly and perfect competition. The intermediate level of competition intensity that maximizes investment is found at 63 percent. This means that the maximal level of extensive investment is reached when the operating profit of a firm represents 37 percent of its revenue. Below this level, more competition decreases investment. The inverted-U is valid for different regions of the World, with an investment maximizing intensity of competition reached at 65 percent for Asia-Pacific, 66 percent for Western Europe, and 69 percent for Africa. It is also valid for investment in the network quality. Here the quality is measured by the download speed of the mobile network. The intensity of competition which maximizes investment in newtork quality is found at 71 percent.

Moreover, our results shows that a part of the downward sloping part of the relationship between the intensity of competition and investment stems from the threat of entry, measured by the number of planned entries into the market. More specifically, the investment maximizing intensity of competition is 4 percentage points higher when we control for the number of planned entries into the market. The point estimate of this latter variable is negative and significant, implying that the threat of entry into the market reduces the incentive for investment in the mobile network infrastructure. Finally, we also find that unlike the extensive investment, the intensive investment; that is the ratio of investment over revenue, has a U-shaped relationship with the intensity of competition. This is because the revenue of the mobile network operators is maximized at the investment maximizing intensity of competition.

Nonetheless, this empirical evidence cannot be generalized to other sectors. Actually, the mobile telecommunications industry is characterized, like the whole information technologies sector, by a very high rate of technological progress, more than 20% for more than a century according to (Koh and Magee, 2006). This high rate of technological progress implies that the size of innovation is large in the mobile telecommunications industry. To highlight the role of the size of innovation in driving the shape of the relationship, we propose a theoretical model in which investment in a new technology generates a stream of monopoly profit for the investing firm over a certain period. However, this period is reduced by competition. Technological progress shifts downward the marginal cost of production. Provided that the size of innovation is large enough, the model yields a non-monotonous relationship, particularly an inverted-U, between competition and investment, consistently with the empirical findings for the mobile industry. In addition, the size of innovation reduces the investment maximizing intensity of competition. More generally, we show that the inversion of the curve is more likely to occur under high technological progress as observed in the mobile telecommunications industry.

The rest of the paper is organized as follows. Section 2 provides a summary of the related literature, section 3 describes the industry, the dataset and the variables, section 4 presents the empirical evidence and section 5 provides a theoretical framework that gives the insight of the inverted-U shaped curve for a highly innovative industry. The final section discusses the results and provides some concluding remarks.

2 Related Literature

Most of the papers dealing with the relationship between competition and investment focus on investment in RD (innovation). This feature of the literature differs from this paper which rather focuses on investment in quality improving technologies and infrastructures. However, as emphasized by Mathis and (Mathis and Sand-Zantman, 2014), once we abstract from property rights issues, there is no difference between investment in RD and in other types of assets. Therefore, this literature review shall mainly rely on the findings from the literature on the impact of competition on innovation.

Actually, as reviewed by (De Bondt and Vandekerckhove, 2012), the relationship between competition and investment is a long standing debate owing to the critical role of investment for economic growth. Two conflicting views reside at the core of this debate. On the one hand, the Schumpeterian view pioneered by Schumpeter (1942) points out the role of firm size, financial constraints and more specifically the incentive of the monopoly to invest more than a firm in a competitive market. This latter is driven by the eficiency effect as epitomized by the paper of Gilbert and Newbery (1982). On the other hand, the Arrow's view developed by Arrow (1962) emphasizes that the monopolist has less incentive to innovate due to what Tirole (1988) terms the replacement effect.

Several theoretical and empirical papers have been proposed to settle this debate. From the abundant theoretical literature, it turns out that the relationship between competition and investment can be of any type (Schmutzler, 2013). It actually depends on the theoretical parameterization of competition, the mode of competition and the nature of investment. This conclusion is strongly supported by the multitude and somehow contradictory empirical findings. For instance, using data of British firms, Blundell, Griffith, and Van Reenen (1999) found that larger firms innovate more; while firms in more concentrated markets innovate less. Likewise, Kraft (1989) found a negative relationship between the number of competitors and the percentage of sales attributable to new products, whereas Nickell (1996) identified a positive relationship between competition and innovation for British firms. In his paper, competition is measured by the number of competitors and the Lerner index, and innovation is measured by productivity and productivity growth of British firms.

In this unsettled debate, the paper by Aghion, Bloom, Blundell, Griffith, and Howitt (2005) provided both a theoretical and empirical evidence of an inverted-U relationship between competition and innovation. In their paper, the measure of competition is based on the Lerner index and innovation is measured by the citations weighted patents counts of British firms between 1968 and 1997. The underlying mechanism of the inverted-U stems from the reconciliation between the escape-competition effect, corresponding to the Arrow's view, and the Schumpeterian effect whereby laggards firms have no incentive to invest due to a lower incremental profit from catching up with the leader. The Arrow's effect plays out at lower level of competition; whereas the Schumpeterian effect dominates above a certain level of competition; yielding an inverted-U relationship between competition and investment. The central force driving the inverted-U relationship is the technological gap between firms within each industry. These findings have been confirmed by several subsequent empirical papers ; though they emphasize their limitation in terms of causal identification.[1]

Another issue investigated in the literature is the impact of the threat of entry on innovation by the incumbent firms like in Aghion, Blundell, Griffith, Howitt, and Prantl (2009). This paper shows that the threat of entry raises the incumbent's investment in innovation in those industries which are at the technological frontier. In industries lagging behind on the contrary, entry threat reduces investment in innovation.

Currently, there are two important issues that emerge from the literature. First, the lack of robustness in the theoretical results requires a focus on specific industries to identify the actual level of competition which maximizes investment. Second, the interaction between competition and the technological gap across firms play an important role in determining the impact of competition on investment. Both of these issues pose a great deal of challenges to the empirical identification of the nature of the relationship between competition and investment. To the best of our knowledge, there is so far no empirical paper tackling these two issues, probably due to the lack of the required data.

Indeed, most of the cross-industries studies are plagued with the unobserved difference in the presence of basic scientific knowledge (technological opportunities) across industries (Kamien and Schwartz, 1975). To the extent that technological opportunities drive both investment and competition, the empirical estimation of the relationship between competition and investment is biased by the difference in technological opportunities across industries. In addition, the need to focus on specific industries requires panel data on firms from a given industries across several countries. Although many firm level databases have been assembled very recently, they are still hardly accessible to researchers. When they are, the issues of unobserved

[1] See the special issue of the Journal of Industry, Competition and Trade for a list of papers

efficiency and collusion, as well as the reverse causality running from investment to competition require additional information to implement a robust identification strategy.

In this study, we take advantage of the availability of firm level data on mobile network operators (MNO) and the specific role of spectrum policy in determining the intensity of competition to identify the causal impact of competition on investment. The empirical evidence is supported by a simple theoretical model that yields the inverted-U and suggests the size of innovation as one of the drivers of the inverted-U relationship.

3 Background, Dataset and Variables

This section presents the key features that make the mobile telecommunications industry suitable for the identification of the impact of competition on investment. It also presents the available information and the main variables that will be used for the estimation.

3.1 Industry background: The role of spectrum policy and technological progress

There are mainly two features that make the mobile telecommunications industry suitable for identifying the causal impact of competition on investment. First, spectrum policy strongly determines the number of firms and the technology that can be adopted within the market. As a consequence, it affects the intensity of competition in the mobile telecommunications market.

Indeed, electromagnetic spectrum is a key input for the provision of mobile telecommunications services. However, due to their properties in terms of coverage and propagation, the range of spectrum bands that can be used for communications purposes is limited. In addition, there is a risk of interference when similar or neighboring frequency bands are used for different communication purposes. As a result, the electromagnetic spectrum is managed by the government.[2]

[2] At the global scale, the World Radio-communication Conference (WRC) allocates the range of frequency to each region of the World. Thereafter, each country in a given region sets up a government agency which assigns the allocated frequency range to radio-navigation, maritime mobile, broadcasting and land mobile telecommunications.

So often, the governments release additional frequency bands according to their own assessment of the intensity of competition.[3] Each frequency band is split into several spectrum licenses according to the number of network operators that the government is willing to accommodate in the market. In Europe for instance, the 2100 MHz frequency band was split into four spectrum licenses in some markets with initially three operators in order to allow the entry of a fourth operator. Unlike the number of spectrum licenses, the number of frequency bands allocated by the government does not depend on the firms' behavior. It rather directly affects the intensity of competition and the number of firms in the market. As its allocation depends on the assessment of competition by the government, pro-competitive governments are much more likely to release more frequency bands into the mobile telecommunication market at an earlier date. The release of the frequency bands lowers the legal barriers to entry into the industry.

Another reason why the governments may decide to grant additional frequency bands is to respond to the demand for larger bandwidth as new applications appear and require faster data transmission. This is currently the case in most of the developing countries where an increasing traffic over the internet is generated on mobile devices (Pepper, 2013). Frequency bands allocated under these circumstances can generate more competition in the market. As the demand for larger bandwidth is driven by technological progress, which can be viewed as exogenous at a country level, the number of frequency bands is an exogenous shifter of competition in the mobile market.

It turns out that the intensity of competition in the mobile telecommunications industry is partly driven by the allocation of frequency bands by the governments because of their own assessment of competition and the rate of technological progress. This feature makes the number of frequency bands allocated before a given year a good instrumental variable for the intensity of competition in the mobile telecommunication market.[4] In addition to the number of frequency bands, the spectrum management policy determines exogenously the exact year of entry of a firm into the market: network operators decide upon their entry into the market and the year of entry is determined by the government through the process of granting the spectrum license.

The second feature of the mobile telecommunications industry is the significant rate

[3] As of December 2012 at the global scale, the following frequency bands have been assigned to mobile network operators: 1500, 2100, 800, 1600, 1700, 1900, 2500, 2600, 1800, 2300, 3400, 3500, 410, 450, 700 and 850 MHz.

[4] The validity of the instrumental variable is presented in the result section.

of technological progress which drives regular investment in the adoption of new technologies (Koh and Magee, 2006). Each year, equipment providers innovate and release new technologies of mobile telecommunications on the market. The new technology can be a radical change in the provision of telecommunications services or a mere improvement in the transmission of traffic over the network. Radical innovations commonly referred to as a new generations of network, are characterized by a shift in the speed or the protocol of data transmission. So far, there have been four overlapping generations of mobile telecommunications networks (Analog, 2G, 3G and 4G). The overall outcome is a continuous progression of performances.

One consequence of this technological progress is that mobile network operators need to invest regularly in order to upgrade the quality of their network and keep in the race for technology adoption. Another consequence stems from the fact that the new technology is not available in every region for historical reasons owing to their initial level of development. Therefore, a comparison between these regions can provide an insight into the role of technological progress in determining the impact of competition on investment in new technologies.

3.2 Description of the dataset

We build a new dataset by aggregating information from several sources. The first source is the World Cellular Information Services (WCIS) database provided by *Ovum*. This database provides quarterly accounting information on mobile network operators worldwide. This information includes firms' revenue, profit, investment, and their purchase of frequency licenses.

This information is complemented by data on the fixed access lines market share for those mobile networks operators that also operate a fixed network. In order to account for difference across markets in terms of fixed network penetration and regulation, the dataset also include data on household penetration of fixed telephony lines and the share of unbundled local loop access lines. Data on the fixed network were retrieved from the World Broadband Information Service database managed by *Ovum*.

Additional information on the year of entry, merger or exit as well as the year of future entries were also added to the database from the Wireless Intelligence online database. We were also able to obtain data on the characteristics of the mobile networks of each MNOs including the date of launch, the download and upload speed, as well as the list of mobile virtual network operators that it hosts.

Finally we also use the World Development Indicator online database managed by the World Bank to include data on the population density and the size of the population between 15 and 64 years old (working-age population). These data will be useful to control for differences in the cost of network deployment and the size of the markets which are critical for the investment in the mobile telecommunications industry.

The final dataset is cleaned from negative profits and investment as well as extreme values. Under the assumption that the distribution of the intensity of competition should be normal, we define a confidence interval as the sample median intensity of competition plus or minus twice the sample standard deviation. Then observations outside this confidence interval are deemed extreme values. In the end, we obtain an unbalanced panel of 240 firms from 119 countries observed from 2000 to 2014. As a result the main estimation sample contains 4695 observations.

3.3 Description of the Variables

The summary statistics of the main variables are presented in the table 1 in appendix. From these variables, we build the investment both at firm and market levels using the firm's capital expenditures (CAPEX). The CAPEX includes the expenditures in the acquisition of tangible (fixed) assets, the expenditures in the maintenance of the existing tangible assets with a useful lifetime that extends beyond the taxable year, and the expenditures for the purchase of spectrum licenses. As we focus on investment in new technologies, only the first component of the CAPEX, related to the acquisition of tangible asset, is interesting for the estimation. However, we do not observe the expenditures in the maintenance of the existing assets or the expenditures in the purchase of spectrum licenses. One could assign an arbitrary share of the CAPEX to the maintenance expenditures in order to get rid of this component. Under the assumption that this share is the same for all firms, the econometric estimation of the impact of competition on investment would be scaled up by this percentage. In addition, if we use the logarithm of the investment in the regression, the constant share of the CAPEX dedicated to the maintenance shall only affects the constant of the econometric model. Regarding the expenditures in the purchase of spectrum licenses, we could exclude from the sample those observations which correspond to the purchase of license or include into the regression a dummy variable capturing the effect of the purchase of licenses on the CAPEX. In the following, we use the logarithm of the CAPEX as a measure of investment and include dummy variables capturing the effect of the purchase of licenses.[5]

Regarding the intensity of competition, it is built at the firm level based on the Lerner index of monopoly power. Its computation requires information on prices and marginal cost which are not available. Under the assumption of constant marginal cost of production, the ratio between a firm's operating profit and its total revenue is a valid measure of the Lerner index of monopoly power. According to the methodology and definition guide accompanying the WCIS database, the operating profit is measured by the earnings before interest, tax, depreciation and amortization (EBITDA). It is the difference between total revenues and operating expenditures, excluding portions arising through tax, interest payment, depreciation and amortization of assets. The total revenue is the sum of revenue generated through the provision of wireless communications services during a year and the revenue generated from the sales of mobile devices or other equipment sold by the operator during the year. The revenue from the provision of wireless communications services includes revenue from voice and data services over the mobile network, roaming charges, revenue from international direct dialing and interconnection revenue.[6]

If $Comp_i$ denotes the intensity of competition experienced by the firm i, the following equation provides the formula for computing the intensity of competition:

$$Comp_i = 1 - \frac{Ebitda_i}{Revenue_i}$$

In line with the discussion on the role of spectrum policy and technological progress in determining the intensity of competition in the mobile telecommunications industry, we build the number of frequency bands allocated to mobile communications services before a given year for all the 119 countries in our sample. Here we focus on the number of frequency bands but not the number of spectrum licenses to avoid correlation with the number of firms within the market. Actually, the number of licenses is as endogenous as the number of firms within the market; whereas for a given number of spectrum licenses, firms in countries that released more frequency bands should be expected to experience higher intensity of competition. This ad-

[5]We obtain similar results when we exclude from the sample, observations corresponding to the purchase of licenses. However, the instruments are less strong due to the fall in the sample size.

[6]Actually, the service revenue is a better measurement of the revenue as it only includes revenue from the provision of retail access to the mobile network. However, based on data from firms for which we have both total and service revenue, we found that the revenue from the sales of mobile devices and equipment accounts for less than 1 percent of the total revenue.

ditional intensity of competition is exogenous with respect to investment as it is generally driven by government seeking more revenue or the exogenous rate of technological progress in the mobile industry. The number of frequency bands allocated before a given year is a cumulated variable. When new frequency bands are released for mobile communications in a country, there are added up to the number of frequency bands released before that year to make up the variable. It actually characterizes the extent of the regulatory barriers to entry into the mobile telecommunications industry. The higher the number of frequency bands released before a given year, the lower the barrier to entry into the industry.

To ensure comparability across markets regarding the joint determinants of investment in new mobile network technologies and the intensity of competition, we define the logarithm of the size of the working age population and the population density as proxies for the market size and the cost of network deployment respectively. We also build a dummy variable characterizing country with local loop unbundling regulation when there is a fixed network, and a set of regional dummy variables to capture regions fixed effects such as the difference in the standards of living or the willingness to pay for mobile communications services across markets. Similarly at the firm level, we build dummy variables characterizing respectively an MNO which is also the incumbent fixed network operator, an MNO which hosts an MVNO, and an MNO which has purchased spectrum license during a given quarter.

4 Empirical Evidence

4.1 Descriptive statistics and Non-parametric estimation

Figure 2 in appendix presents the scatter plot of the relationship between the intensity of competition and investment. This figure exhibits and inverted-U relationship between the intensity of competition and the logarithm of investment; as evidenced by the quadratic fit from the data. The inverted-U observed from this figure results from the parametric assumption about a quadratic relationship between the intensity of competition and investment.

In order to identify the actual relationship in the data without making any parametric assumption, we proceed by estimating the non-parametric relationship based on a local polynomial smoothing and a locally weighted scatter plot smoothing. The results of these estimation are presented in figures 3 and 4 respectively. In both estimations, we partial-out the effect of the size of the market; that is we use the residuals plus the constant from the regressions of investment and competition on the size of the working-age population. It turns out that there is indeed an inverted-U relationship between the intensity of competition and the investment in new technologies.

The descriptive statistics provided by figures 2, 3 and 4 provide some insights into the potential impact of the intensity of competition on investment. However, they are not sufficient to draw any causal impact of competition on investment. They are actually plagued with issues related to omitted variables biases and reverse causality. Figures 5 and 6 in appendix provide evidence about the exogenous drivers of the intensity of competition that will be used to identify its causal impact on investment. The first figure presents a positive relationship between the number of frequency bands released and the intensity of competition within a market. The second figure shows that firms that enter the market later face higher intensity of competition on average. Altogether, these figures show that the regulation of entry and access to spectrum drive the intensity of competition experienced by MNOs.

4.2 Econometric models and identification strategies

In order to estimate the causal impact of the intensity of competition on investment, we adopt a two-stage structural approach based on reduced-form models. In the first stage, competition is modeled as a linear function of the regulatory variables identified in the background section. Then, in a second stage, investment is expressed as a function of competition. The coefficients of the resulting models have been estimated by implementing an instrumental variable approach based on the Generalized Method of Moment (GMM) (Hansen, 1982). Typically, the intensity of competition and its square are deemed endogenous and instrumented by the cumulated number of frequency bands and the year of entry into the market. All estimations correct for arbitrary heteroskedasticity and autocorrelation using the Bartet Kernel of bandwidth 2. We implement the weak instruments test using the instrumental variables Stata routine proposed by Baum, Schaffer, and Stillman (2007). The Kelibergen-Paap Wald rank F-statistics are compared to the critical values tabulated by Stock and Yogo (2002) to test the weakness of the instruments. The details of the modeling are presented as follow:

Across similar markets and firms, the intensity of competition is determined by the cumulated number of frequency bands released and the year of entry allowed by the regulator. The cumulated number of frequency bands acts as a proxy for the barrier to entry into the mobile telecommunications market. The larger the number of cumulated frequency bands, the lower is the barrier to entry and the fiercer is the competition within the market. Similarly, firms that enter later into the market face more competitors, and therefore experience higher intensity of competition. More formally, the intensity of competition is linearly related to these exogenous competition shifters as:

$$Comp_{iq} = \alpha_0 + \alpha_1 freq_{iq} + \alpha_2 entry_i + \alpha X_q + \varepsilon_{iq} \tag{1a}$$

$$Comp^2_{iq} = \beta_0 + \beta_1 freq_{iq} + \beta_2 entry_i + \beta X_q + \epsilon_{iq} \tag{1b}$$

These two equations determine the exogenous change in competition and represent the first-stage of the estimation of the impact of the intensity of competition on investment in new technologies. $Comp_{iq}$ is the intensity of competition experienced by firm i during the quarter q. $freq_{iq}$ is the cumulated number of frequency bands released in the market of firm i before the quarter q (included). $entry_{iq}$ is the year of entry of firm i into the market. Finally, X_q is a vector of control variables to ensure similarities across markets and firms. It includes the logarithm of the working-age population, the logarithm of the population density, four dummies characterizing markets with local loop unbundling, incumbent fixed network operators, firms hosting an MVNOs and the purchase of spectrum license. The vector X_q also includes a quarterly trend and regional fixed effects.

The second stage of the estimation considers various outcomes to measure the investment in new technologies, namely the extensive investment, the extensive investment in network quality and the intensive investment. Given the results of the non-parametric estimation, we postulate a quadratic relationship between the intensity of competition and the investment.

The following equation estimates the impact of the intensity of competition on the extensive investment:

$$lninv_{iq} = \gamma_0 + \gamma_1 Comp_{iq} + \gamma_2 Comp^2_{iq} + \gamma X_q + \mu_{iq} \tag{2}$$

Where $lninv_{iq}$ is the logarithm of investment of firm i during quarter q, and μ_{iq} are the residuals of model.

The impact of the intensity of competition on investment in new technologies is estimated through the coefficients γ_1 and γ_2. If the inverted-U relationship observed from the descriptive statistics is valid, these coefficients should be statistically significant and respectively positive and negative. In this case, the investment maximizing intensity of competition (IMIC) is estimated as:

$$IMIC = -\frac{\gamma_1}{2\gamma_2}$$

The confidence interval of the investment maximizing intensity of competition is estimated using the delta method.[7] An estimation algorithm is developed in Stata by Hole (2007).

We investigate the heterogeneous impact of competition on investment by estimating equation (2) on the sub-samples of regional observations. In particular, the estimations are based on the sub-samples of observations from Asia-Pacific, Western Europe and Africa. In the other regions, there were not sufficient observations to make the statistical inference, or the power of the instruments is not strong enough. The following equations have been estimated to examine the heterogeneous effects of competition on investment.

$$lninv_{iq} = \gamma_0 + \gamma_1 Comp_{iq} + \gamma_2 Comp_{iq}^2 + \gamma X_q^{'} + \mu_{iq} \tag{3a}$$
$$lninv_{iq} = \gamma_0 + \gamma_1 Comp_{iq} + \gamma_2 Comp_{iq}^2 + \gamma X_q^{'} + \mu_{iq} \tag{3b}$$
$$lninv_{iq} = \gamma_0 + \gamma_1 Comp_{iq} + \gamma_2 Comp_{iq}^2 + \gamma X_q^{'} + \mu_{iq} \tag{3c}$$

Equations (3a), (3b) and (3c) have been estimated on the sub-sample of observations from Asia-Pacific, Western-Europe and Africa respectively. The main difference between these equations and the equation 2 is the set of controls $X_q^{'}$ which no longer includes regional dummies.

To disentangle between investment in the extension of the network and the investment in upgrading the quality of the network through the adoption of new technologies, we also estimate the model (2) above but replace the logarithm of investment by the logarithm of the predicted investment in new technologies. This latter results from the predicted values of the linear regression of the capital expenditures

[7] Typically, the delta method linearizes an estimator using the Taylor expansion around its mean in order to compute its variance. See Oehlert (1992) for details.

on the maximum download speed allowed by the mobile networks of each network operator.[8] If $lninvtech_{iq}$ the predicted investment in new technologies, the model then writes:

$$lninvtech_{iq} = \gamma_0 + \gamma_1 Comp_{iq} + \gamma_2 Comp_{iq}^2 + \gamma X_q + \mu_{iq} \tag{4}$$

One of the hypotheses emphasized in the literature to explain the downward sloping part of the inverted-U is the negative impact of the threat of entry on investment. In order to test this hypothesis, we estimate the following model:

$$lninv_{iq} = \gamma_0 + \gamma_1 Comp_{iq} + \gamma_2 Comp_{iq}^2 + \lambda E[\xi_{iq}/Comp_{iq}] + \gamma X_q + \mu_{iq} \tag{5}$$

$E[\xi_{iq}/Comp_{iq}]$ is the threat of entry given the current intensity of competition. In the econometric estimation, we use the number of entries planned, as of the last quarter of observation (Q1 of 2014), as a proxy for the threat of entry.

On top of looking at the extensive investment, one can also be interested as in (Vives, 2008) in identifying the impact of the intensity of competition on the intensive investment; that is the ratio of investment over revenue. The following equation presents the model to be estimated for that purpose:

$$\frac{capex_{iq}}{revenue_{iq}} = \delta_0 + \delta_1 Comp_{iq} + \delta_2 Comp_{iq}^2 + \delta X_q + \mu_{iq} \tag{6}$$

4.3 Results

The results of the estimation of the models (1a) and (1b) are presented in the first two columns of table 3. As suggested by the descriptive statistics, they confirm that the regulation affects the intensity of competition experienced by firms in the market. More specifically, the release of an additional frequency bands is predicted to increase the intensity of competition by 0.1 percentage point. Likewise, entering into the market a year later raises the intensity of competition experienced by a firm by 0.4 percentage point. These effects are statistically significant at 1% level.

The effect of this change in competition, as predicted by regulation, on the investment is estimated from model (2). The results of this estimation are presented in

[8] The download speed is nil when the best available network is 2G.

the first column of table 4. The sign and significance of the point estimates of the competition variables indicate that there is an inverted-U relationship between competition and investment in the mobile telecommunications industry. More precisely, as long as the intensity of competition is below 63 percent, an increase in the intensity of competition raises investment. Above this level, any further increase in the intensity of competition decreases investment. For instance, 1 percentage point increase in the intensity of competition raises investment by 7.2 percent at the first quartile of the intensity of competition (53%); but decreases investment by 6.7 percent at the third quartile of the intensity of competition (72%). The 95 percent level confidence interval of the investment maximizing intensity of competition ($IMIC$) lies between 57 and 69 percent.

The heterogeneous impact of the intensity of competition on investment is estimated from models (3a), (3b) and (3c). These models are used to estimate the impact of the intensity of competition on investment respectively in Asia-Pacific, Western Europe and Africa. The results are presented in the corresponding columns of table 4. They show that the inverted-U relationship between the intensity of competition and investment still holds in these three regions. However, there are some differences with respect to the $IMIC$ and the slope of inverted-U curves.

Indeed, not only is the $IMIC$ higher in these regions than in the whole World; but also it is higher in those regions which are still extending their network coverage. This is the case for instance in Africa, where the penetration rates of both the 2G and 3G network are still very low at 63 and 9 percent respectively (See figures 7 and 8). Likewise, the $IMIC$ is slightly higher in Western Europe where the coverage of the 3G network is under way. These results suggest that the relationship between the intensity of competition and investment tends to be monotonously increasing in absence of technological progress. In other words, the rate of technological progress is potentially one of the drivers of the $IMIC$: the lower the rate, the higher the $IMIC$. This statement will be further investigated in a theoretical model in next section.

In addition, on the one hand, at the first quartile of the intensity of competition, a further increase by 1 percentage point raises investment by 17.8 percent in Asia-Pacific, 6.2 percent in Western Europe and 7.1 percent in Africa. On the other hand, at the third quartile of the intensity of competition, the effect of the same increase in competition decreases investment by 10 percent in Asia-Pacific, 2.7 percent in Western Europe and 1.5 percent in Africa. Thus, the slope of the inverted-U curve is steeper in Asia-Pacific than in the other two regions.

As expected, the capital expenditures is on average 12 percent higher when a firm purchases frequency licenses during a quarter (column (2) of table 4). While this effect extracts the effect of the purchase of licenses from the estimated impact of the intensity of competition on investment, it does not help disentangle between the effects on the investment in network extension from the effect on the investment in upgrading the quality of the network through the adoption of new technologies. The estimation results of the model (4) presented in the corresponding column of table 4 provide an insight into the impact of the intensity of competition on the investment in network quality. They show that there is also an inverted-U relationship between the investment in the quality of the network and the intensity of competition. However, the level of the $IMIC$ is 8 percentage higher compared with the level obtained with the overall investment in both the infrastructure and the quality of the network. With a probability of 95 percent, the $IMIC$ of the investment in the network quality is comprised between 66 and 76 percent; with a point estimate at 71 percent. This result suggests that investment in network extension falls at lower level of the intensity of competition compared to investment in network quality.

The impact of the threat of entry on investment is estimated from model (5) and the results are presented in the corresponding column of table 4. It turns out that the threat of entry, as measured by the number of planned entries, has a negative impact on investment. That is, the higher the number of planned entries, the lower the current level investment. In terms of magnitude, the planning of an additional entry into the market lowers investment by 4 percent on average. One consequence of this effect is that the slope of the inverted-U curve is underestimated below the $IMIC$ and overestimated above the $IMIC$. For instance, a one percentage point increase in the intensity of competition raises investment by 13.8 percent at the first quartile but decreases investment by 5.2 percent at the third quartile. Compared to the prediction from the model (2), the estimated impact was underestimated (7.2 percent) at the first quartile and overestimated (6.7 percent) at the third quartile. More interestingly, the $IMIC$ turns out to be 4 percentage points higher when we control for the effect of the threat of entry. This means that the downward sloping part of the inverted-U curve is partly driven by the threat of entry into the market. These results also hold for the investment in network quality. Using the framework provided by Aghion, Blundell, Griffith, Howitt, and Prantl (2009), we can explain this result by the fact that entry in the mobile telecommunications industry is made by technologically advanced firms. However in the meantime, the incumbent firms mostly still rely on the old technology, reducing their incremental rent from investment in the new technologies.

Regarding the impact of the intensity of competition on the intensive investment, the results of the estimation of the model (6) are presented in the last column of table 4. Contrary to the impact of the intensity of competition on the extensive investment, we find a U-shaped relationship between the intensity of competition and investment. Though the intensive investment minimizing intensity of competition is slightly higher than the $IMIC$, the confidence interval is fully included in the confidence interval of the $IMIC$. Actually, the U-shaped stems from the fact that firm's revenue is maximized at the similar level as the extensive investment.[9] As a result, the intensive investment, as the ratio of the extensive investment over revenue, is minimized at similar intensity of competition. The similarity between the relationship between competition and investment and the relationship between competition and revenue is due to the strong and positive correlation between investment and revenue. However, we do not know whether this correlation stems from a causal impact of investment on revenue and particularly how investment affects prices and the quantity of output supplied by firms. The answer to this question has implications for the social welfare effect of the investment.

The set of controls provide some descriptive statistics that characterizes investment in the mobile telecommunications networks. The size of the market as measured by the logarithm of the working age population is positively correlated with both the extensive and the intensive investment. Interestingly, it does not affect the investment in the network quality. The cost of network deployment as proxied by the logarithm of population density is positively correlated with investment. The higher is the population density, the lower is the cost of network deployment and the lower is the capital expenditures (investment). However, the sign of this correlation depends on the regions. For instance, it is rather negative in Western Europe; that is investment is lower in Western Europe countries with lower density.

Local loop unbundling has no effect on the total investment; but negatively affects investment in the quality of the mobile network. This latter effect is contradictory of the findings by Nardotto, Valletti, and Verboven (2012) of the effect of LLU on the quality of the fixed broadband in the UK. Actually, countries without LLU regulation are mostly those in which the fixed network is less developed. Thus the deployment of mobile network with higher download speed is more necessary in these countries. This is potentially the reason why investment in mobile network quality

[9] The estimation results of the impact of the intensity of competition on revenue are available upon request.

is lower in countries with LLU regulation.

The incumbent fixed network operators, on average invest more than the other MNOs, particularly in Asia-Pacific and in Western Europe. The result is still valid for the investment in the quality of the mobile network in Asia-Pacific and in Western Europe. The increase in the point estimate of the dummy variable characterizing FNO from 0.17 to 0.36 and its significance in model (5), suggests that the incumbent FNO's investment in mobile network is much more negatively affected by the threat of entry into the market. Furthermore, the incumbent FNO has lower intensive investment than the other firms mainly due to economies of scale.

The point estimate of the dummy variable characterizing Mobile network operators hosting virtual operators (MVNOs) is positive, meaning that they invest more than the other MNOs which do not host any virtual operators. However, this effect is no longer significant when we control for the threat of entry in model (5) following a fall in the point estimate from 0.25 to 0.13; the standard error being roughly the same. Therefore, the omission of the effect of the threat of entry overestimates the effect hosting an MVNO. In other words, MNOs that host MVNOs are less affected by the threat of entry compared to the other firms.

Finally, the point estimates of the quarterly trend variable suggest that other the period of this study, both extensive and intensive investment have been declining particularly in Asia-Pacific and in Western Europe, due to the increasing network coverage. On the contrary, extensive investment has been increasing so far in Africa, as a result of lower penetration of mobile network. Interestingly, investment in mobile network quality has been increasing at the global scale.

5 A theoretical model to explain the role of the size of innovation in driving the inverted-U shaped

In this section, we present a simple theoretical model to show the role of the potential for technological progress in driving the inverted U shaped relationship between competition and investment. This potential for technical progress is not a parameter of the econometric model that we have tested because our dataset only consider the mobile market where all firms have roughly access to the same technologies. As a result, there is not enough difference between firms or countries to test it as one of the underlying mechanism of the inverted-U. However, technological progress is particularly high in mobile telecommunication sector. Koh and Magee (2006) found a 20 to 30 percent rate of technological progress for information technologies for more than a century. This is far above most of other sectors like energy where technological progress is close to 6 percent, and far above the rate of global productivity growth often under 5 percent. This is probably one of the reasons why the relationship between competition and investment is inverted U-shaped in mobile telecommunication industry.

In the literature, the main model rationalizing the inverted-U is the one provided by Aghion, Bloom, Blundell, Griffith, and Howitt (2005) (ABBGH). This model does not help explaining our empirical evidence as it is derived from an endogenous growth model. It is therefore a general equilibrium model in which the main feature driving the inverted-U is the technological gap between firms within the industries. In addition, when the technology is normalized and available to all firms within an industry, there is hardly a technological gap between them.

This model encloses both the escape-competition and the Schumpeterian effects like in the ABBGH's model. However, while the modeling of the escape competition effect is alike, the Schumpeterian effect, which decreases the incentive to invest with the intensity of competition, is modeled as a reduction in the duration over which a first mover enjoys its investment. This is not the same as in the ABBGH model, whereby the Schumpeterian effect is driven by the technological gap. By doing so, we are able to emphasize the technological progress or the size of innovation as the main driver of the inverted-U relationship within an industry.

5.1 Settings of the model

Consider a symmetric Bertrand duopoly with differentiated goods, produced at constant marginal cost c. The differentiation parameter $\theta \in [0, 1]$ stands for the intensity of competition. When $\theta = 0$ the goods are independent and each firm enjoys a monopoly over its product. When $\theta = 1$ goods are perfect substitutes, in which case the Bertrand competition yields the perfect competition outcome. Typically, an increase in θ implies a rise in competition.

We consider an infinite horizon over which innovation occurs once. This horizon is split into three periods during which firms first invest and then compete in the product market.

Period 0: Symmetric market

During this period there is no innovation and both firms incur the marginal cost $\bar{c}$ and earn the duopoly profit $\pi^d(\bar{c};\theta)$.

Period 1: Innovation and the first mover's investment

At the beginning of period 1, an exogenous innovation occurs; providing a new technology which is available to both firms. The cost of this technology is decreasing over time and investment in the new technology reduces the marginal cost of production from $\bar{c}$ to $\underline{c}$, with $\bar{c} > \underline{c}$.

Given the innovation, one of the firms invests in the new technology; this is the first-mover. Then, they both compete in price to supply the differentiated good until the end of this period.

During this period, the reduced form of the profit of the first mover writes: $\pi^1(\underline{c};\theta)$ and the profit of the second firm writes $\pi^1(\bar{c};\theta)$. As such, the intensity of competition is not affected by the investment in the new technology.

Period 2: The follower's investment

The second firm, the follower, invests in the new technology at the beginning of period 2. As a result, both firms now incur the marginal cost $\underline{c}$ and earn the duopoly profit $\pi^d(\underline{c};\theta)$.

The lag between periods 1 and 2 represents the reaction time of the follower to the investment of the leader. This duration is denoted T and assumed to be exogenous. We assume that the more the products are substitutes, the quicker the reaction of the follower; that is, T is a decreasing function of θ: $T'(\theta) < 0$. In particular, T tends to infinity when θ tends to zero.

Note that the settings of the model accord well with the investment and competition in the mobile telecommunications industry.

Now that the settings of the model are in place, our goal is to show how the potential for technological progress, measured by the impact of the innovation on marginal cost of production and denoted $\tau = \bar{c} - \underline{c}$, affects the relationship between investment and the intensity of competition. More specifically, we first determine the nature of the relationship between the intensity of competition and investment by relying on the incentive to invest in the new technology. This incentive is characterized by the additional flow of profit generated by investment over the whole period. Then, we study how the relationship is affected by the potential for technological progress τ.

Let's f and g denote this instantaneous and constant additional flow of profit over the first and second periods respectively:[10]

$f(\theta) = \pi^1(\underline{c}, \theta) - \pi^d(\bar{c}, \theta)$ and $g(\theta) = \pi^d(\underline{c}, \theta) - \pi^d(\bar{c}, \theta)$

$f(\theta)$ and $g(\theta)$ are respectively increasing and decreasing function of θ.

The total incremental flow of profit generated by investment by the first mover writes:

$$V(\theta) = \int_0^T e^{-rt} f(\theta) dt + \int_T^\infty e^{-rt} g(\theta) dt$$

This is equivalent to:

$$V(\theta) = \frac{1}{r}[\phi(\theta)f(\theta) + (1 - \phi(\theta))g(\theta)]$$

With r, the discount rate and $\phi(\theta) = 1 - e^{-rT(\theta)}$.

Although we do not know the explicit expression of $V(\theta)$, we are able to derive the shape of its curve by studying the sign of its derivative at the extreme of the intensity of competition. This derivative writes:

$$\frac{\partial V}{\partial \theta} = \frac{1}{r}\Big[\frac{\partial \phi}{\partial \theta}(f(\theta) - g(\theta)) + (1 - \phi(\theta))\frac{\partial g}{\partial \theta} + \phi(\theta)\frac{\partial f}{\partial \theta}\Big] \tag{7}$$

5.2 The inverted-U and the role of the potential for technological progress

Given that $T(\theta)$ is decreasing, so is the derivative of $\phi(\theta)$: $\frac{\partial \phi}{\partial \theta} < 0$. In addition, $f(\theta) - g(\theta) \geq 0$ because the efficient duopolist's profit is higher than the profit of the symmetric duopoly. Therefore, the first term within the bracket is negative; that is $\frac{\partial \phi}{\partial \theta}(f(\theta) - g(\theta)) \leq 0$.

Moreover, given that $f'(\theta) \geq 0$, $g'(\theta) \leq 0$ and $0 \leq \phi(\theta) \leq 1$, we have that $(1 - \phi(\theta))\frac{\partial g}{\partial \theta} \leq 0$ and $\phi(\theta)\frac{\partial f}{\partial \theta} \geq 0$.

[10] The expression of the instantaneous profit over the second period stems from the fact that the duration $T(\theta)$ is exogenously determined by the intensity of competition. Should the timing of investment chosen by firm, then $g(\theta) = \pi^d(\underline{c}, \theta) - \pi^1(\underline{c}, \theta)$.

The sign of the derivative of $V(\theta)$ at the extreme of the intensity of competition turns out as follow;

■ When $\theta = 0$, the products are independent and both firms are monopolists in each product's market. In this case, $f(0) = g(0)$ and $\phi(0) = 1$. As a result, $\frac{\partial V}{\partial \theta} = \frac{1}{r}\frac{\partial f}{\partial \theta} > 0$. The derivative of the incentive to invest is positive when the market is monopolistic.

■ When $\theta = 1$, the positive term in the brackets of equation (3) is lower than the negative terms and $\frac{\mathrm{d}V}{\mathrm{d}\theta} < 0$, only if $\phi(1)$ is sufficiently small. This condition means that the duration of the first mover's advantage is sufficiently small under perfect competition. Under this condition, the derivative of the incentive to invest is negative at the perfect competition.

It turns out from these two results that $V(\theta)$ is locally increasing at $\theta = 0$ and locally decreasing at $\theta = 1$, when $\phi(1)$ is sufficiently small. Therefore, there can be a value θ^* in the interval [0,1] that maximizes $V(\theta)$ and therefore an inverted-U relationship between competition and investment can arise. Otherwise, if $\phi(1)$ is large, the positive term can be higher than the negative ones and $\frac{\partial V}{\partial \theta} > 0$. In that case, investment is maximized under perfect competition.

A first note from this result is that the duration of the first mover's advantage under perfect competition determine whether or not relationship between competition and investment is inverted-U. Indeed, this duration is a decreasing function of the potential for technological progress τ. Hence, the potential for technological progress decreases the incentive to invest because of a lower duration of the first mover advantage under high intensity of competition. This effect is similar to the Schumpeterian effect. On top of this effect, we can observe that the difference $f(\theta) - g(\theta)$ represents the magnitude of the first mover advantage. It is an increasing function of the potential for technological progress τ. This is the escape-competition effect.

The Schumpeterian effect tends to reduce the positive term of equation (3); whereas the escape-competition effect tends to raise the negative ones. As a result, the larger the potential for technological progress, the more likely is the inverted-U. This is precisely because the first mover enjoys higher rent from investing; but over a smaller period.

5.3 An illustration with the Singh and Vives' demand function

The inverse demand function of firm i writes: $p_i = 1 - \frac{1}{1+\theta} q_i - \frac{\theta}{1+\theta} q_j$, where $0 \leq \theta \leq 1$ (See(Singh and Vives, 1984)). If c_i and c_j denote respectively the constant marginal cost of production of firm i and j, the Nash-equilibrium of the Bertrand competition with differentiated products yields:

$$p_i(\theta) = \frac{(2-\theta^2) + 2 * c_i - \theta(1-c_j)}{(2-\theta)(2+\theta)}$$

$$\pi_i(\theta) = \frac{[(2-\theta^2)(1-c_i) - \theta(1-c_j)]^2}{(4-\theta^2)^2(1-\theta)}$$

Before investment in the new technology, the market is symmetric and both firms incur the marginal cost $\bar{c}$ and earn the profit:

$$\pi^d(\bar{c}, \theta) = \frac{(1-\theta)(1-\bar{c})^2}{(2-\theta)^2}$$

The first-mover invest in the new technology and decreases it cost from $\bar{c}$ to $\underline{c}$ and earns the asymetric profit which writes:

$$\pi_i^1(\underline{c}, \theta) = \frac{[(2-\theta^2)(1-\underline{c}) - \theta(1-\bar{c})]^2}{(4-\theta^2)^2(1-\theta)}$$

At date T, the follower reacts and the market becomes symmetrical again. Then, each firm incur the cost $\underline{c}$ and earn the symmetric profit:

$$\pi^d(\bar{c}, \theta) = \frac{(1-\theta)(1-\underline{c})^2}{(2-\theta)^2}$$

The instantaneous profits before and after the reaction of the follower writes:

$$f(\theta) = \frac{(2(1-\bar{c})\tau + \tau^2)(2-\theta^2)^2 - 2\theta(2-\theta^2)(1-\bar{c})\tau}{(4-\theta^2)^2(1-\theta)}$$

$$g(\theta) = \frac{(1-\theta)(2(1-\bar{c})\tau + \tau^2)}{(2-\theta)^2}$$

We choose an arbitrary duration of the $\phi(\theta) = 1 - \lambda\theta$, with $0 \leq \lambda \leq 1$. This function is decreasing in the intensity of competition θ and yields the required properties for the reaction time $T(\theta)$.[11]

The graphical illustration of the relationship between competition and investment based on this model is presented below:

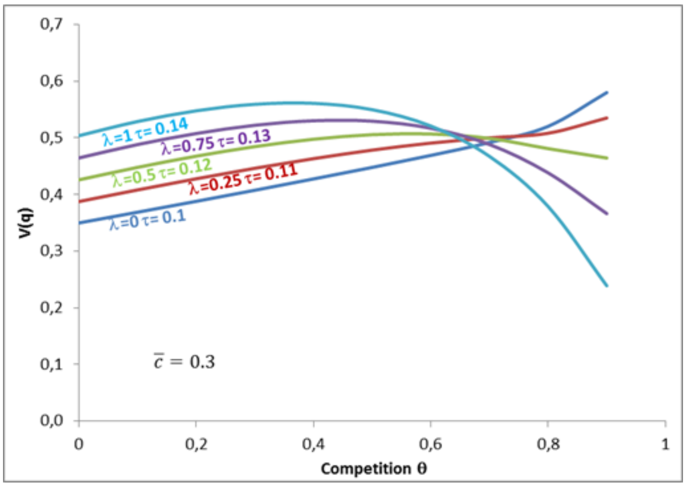

Figure 1: Competition and investment using Singh and Vives' demand function

[11]Theoretically, $\phi(\theta) = 1 - e^{-rT(\theta)}$. Thus, the corresponding reaction time is $T(\theta) = -\frac{ln(\lambda\theta)}{r}$ and it is decreasing in the intensity of competition.

6 Conclusion

In this paper, we use firm level data and an instrumental variable estimation strategy to identify the causal impact of the intensity of competition on investment in the mobile telecommunications industry. We find an inverted-U relationship between competition intensity and investment. The investment maximizing intensity of competition stands at 63 percent. This result is qualitatively robust across regions of the World, for investment in network quality and the threat of entry.

To explain this result, we derive a simple model that embeds both the escape competition effect and the Schumpeterian effect. Provided that the size of innovation is large enough, this model yields an inverted-U relationship between competition intensity and investment, consistently with the empirical findings. That is, at low level of competition intensity, the escape competition effect dominates over the Schumpeterian effect. However, above certain intermediate level of competition, the escape competition effect is overtaken by the Schumpeterian because of the smaller duration over which any first mover enjoys the monopoly rent generated by investment.

One of the key features of this model is the fact that the inversion of the curve depends on the size of innovation, measured by the impact of investment in new technologies on the marginal cost of production. The model implies that the investment maximizing intensity of competition is higher in industries with smaller size of innovation. Therefore, the significance of technological progress in the mobile telecommunications industry, as found in the literature, can partly explain the inverted-U. Otherwise, an increasing relationship would be more likely to emerge.

These results suggest that policymakers need to consider the profit margin, the ratio of the EBITDA over revenue, of the mobile network operators before allowing an entry or a merger in the industry. When the profit margin is below the investment maximizing profit margin, then a merger is more desirable than an additional entry. On the contrary, when the profit margin is above its "optimal level", an additional entry may generate more investment incentive than a merger. In the mobile network industry, regulators often plan a new entry several years in advance as a disciplining device for the incumbent mobile network operators. Our results show that this strategy lowers the investment of the incumbent operators.

These policy implications raise the questions of whether there is an investment maximizing number of mobile network operators. For further research, we would like to understand how the market structure affects the investment incentives and how it depends on the asymmetry between the firms. Given the dynamic feature of the mobile industry, a study of the impact of entry and merger on pricing and investment over several years would provide an additional insight into the impact of competition in this industry. Finally, a complementary view to the main question is to study how cooperation in investment such as network sharing interplays with the effect of the number of firms and more generally market dynamics.

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A Appendix

A.1 Summary and Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Revenue	4695	957,4	2241,3	2,5	24808,0
Fixed market share (%)*	1683	29,2	25,2	0,0	100,0
Profit (Ebitda)	4695	354,2	937,2	0,1	10841,8
Investment (Capex)	4695	153,4	458,8	1,0	6705,9
Market size**	841	39,6	116,6	0,4	990,5
Population density	841	283,0	1039,8	2,4	7589,1
Percentage of LLU lines ***	763	1,9	5,2	0,0	37,0

Revenue, Profit and Investment are in millions constant dollars of the first quarter of 2014.
(*) Applies to mobile operators that also operate a fixed network.
(**) Market size is measured by the size of the population between 15 and 64 years old, reported in millions.
(***) Applies to countries with a Local loop unbundling regulation.

Table 1: Summary Statistics

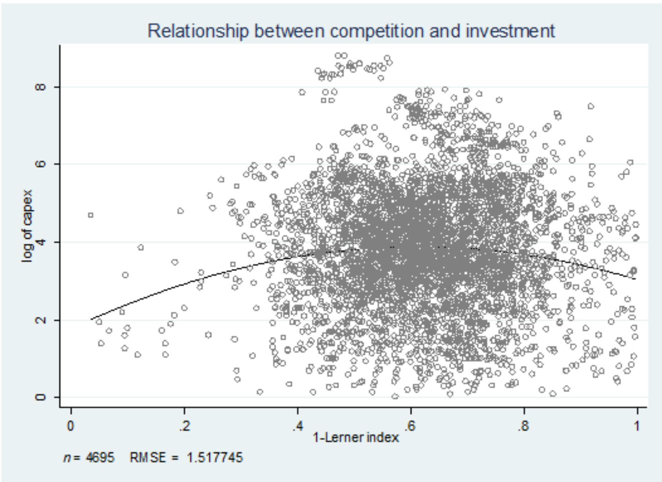

Figure 2: Relationship between competition and investment

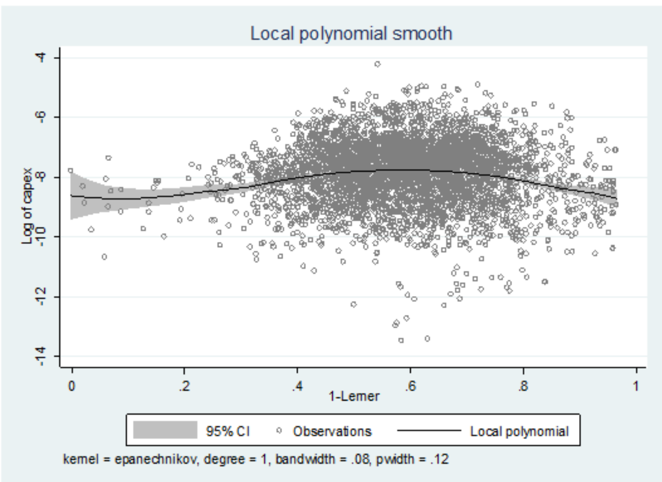

Figure 3: Local polynomial smoothing

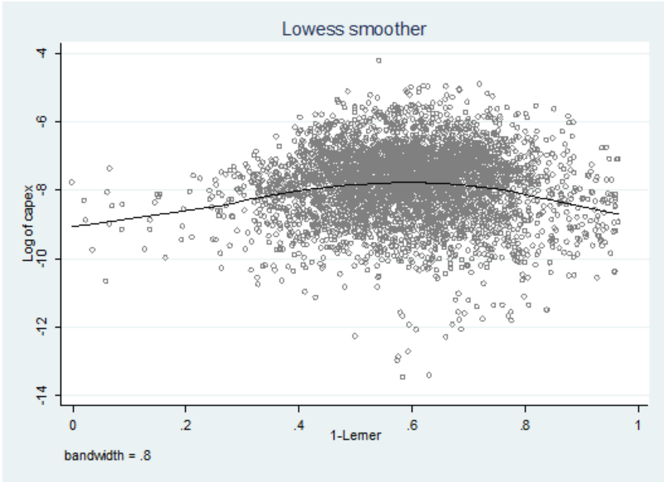

Figure 4: Locally weighted scatterplot smoothing

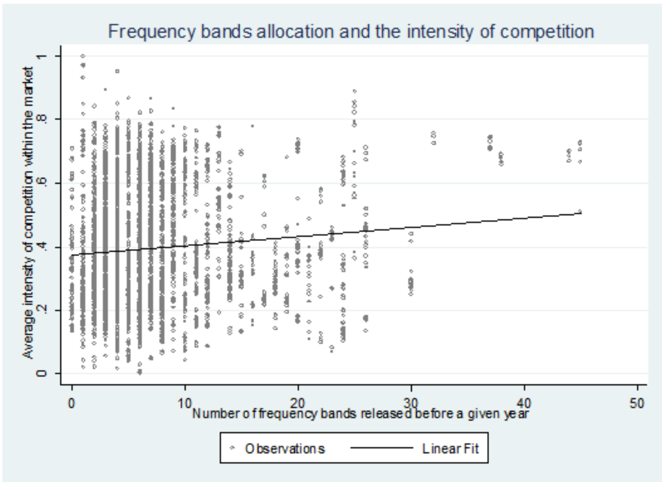

Figure 5: Relationship between the number of frequency bands released and the intensity of competition

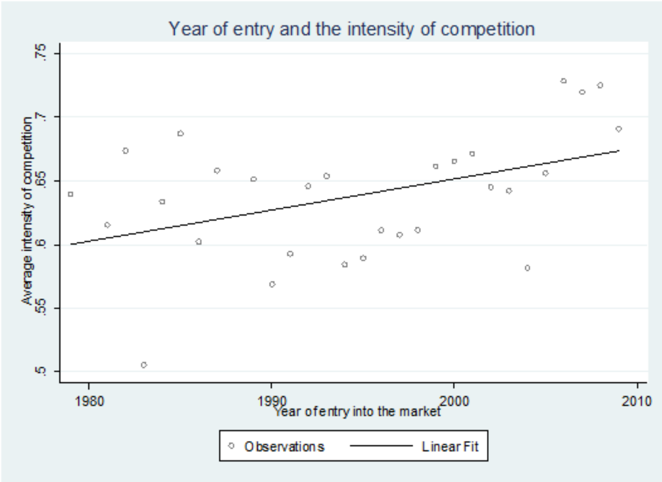

Figure 6: Relationship between the year of entry and the intensity of competition

A.2 Caracteristics of the Regions

Regions	Countries
Africa *32 countries* *711 observations*	Algeria, Cameroon, Congo, Cote d'Ivoire, Democratic Republic of Congo, Egypt, Ghana, Guinea, Guinea Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mozambique, Namibia, Niger, Nigeria, Rwanda, Senegal, Sierra Leone, South Africa, Sudan, Swaziland, Tanzania, Tunisia, Uganda, Zambia, Zimbabwe
Americas *10 countries* *321 observations*	Argentina, Brazil, Chile, Colombia, Ecuador, Mexico, Paraguay, Peru, Uruguay, Venezuela
Asia Pacific *16 countries* *862 observations*	Australia, Bangladesh, Cambodia, China, Hong Kong, India, Indonesia, Japan, Korea, Malaysia, New Zealand, North Korea, Pakistan, Philippines, Singapore, Thailand
Eastern Europe *27 countries* *1130 observations*	Albania, Armenia, Belarus, Bulgaria, Croatia, Czech Republic, Estonia, Georgia, Hungary, Kazakhstan, Kirghizstan, Kosovo, Latvia, Lithuania, Macedonia, Moldova, Montenegro, Poland, Romania, Russia, Serbia, Slovak Republic, Slovenia, Tajikistan, Turkmenistan, Ukraine, Uzbekistan
Western Europe *18 countries* *1245 observations*	Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Israel, Italy, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, United Kingdom
Middle East *10 countries* *236 observations*	Afghanistan, Bahrain, Iran, Iraq, Jordan, Kuwait, Palestine, Saudi Arabia, Syria, Yemen
USA/Canada	Canada, USA

Table 2: List of countries within the regions

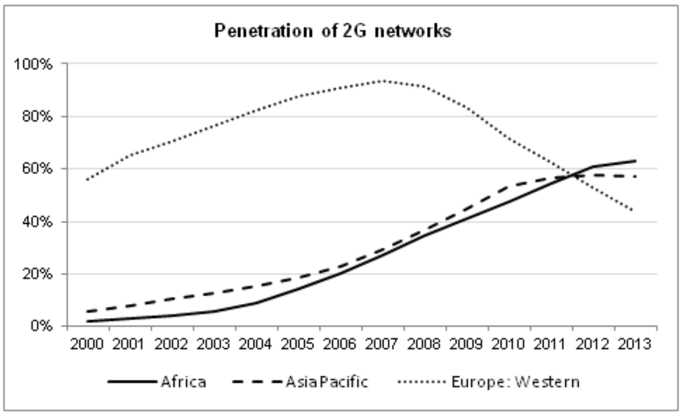

Figure 7: Penetration rate of 2G mobile networks

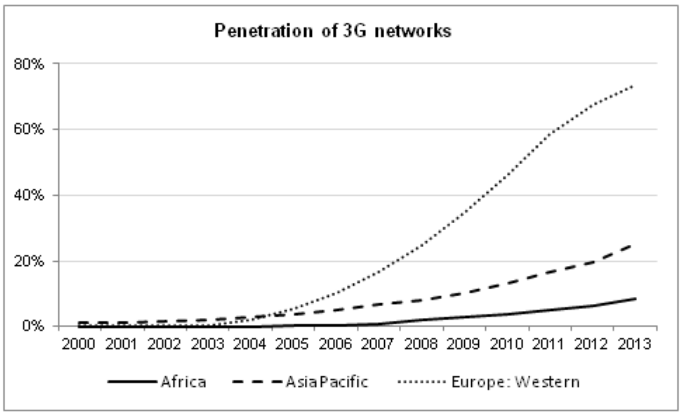

Figure 8: Penetration rate of 3G mobile networks

A.3 Econometric estimation results

	(1-Lerner)	(1-Lerner)^2
	(1a)	(1b)
# frequency bands before a given year	0.001***	0.001***
	(0.000)	(0.000)
Launching year	0.004***	0.007***
	(0.001)	(0.001)
Incumbent FNO	-0.042***	-0.052***
	(0.006)	(0.007)
Log of working age pop.	-0.013***	-0.015***
	(0.002)	(0.003)
Log of pop. density	0.005**	0.006**
	(0.002)	(0.003)
LLU regulation	0.036***	0.041***
	(0.007)	(0.009)
Hosting MVNO	0.021***	0.022***
	(0.005)	(0.007)
Purchase a license	-0.016***	-0.021***
	(0.006)	(0.008)
Quarter	0.000	0.000
	(0.000)	(0.000)
Region fixed effects	v	v
Constant	-7.933***	-12.871***
	(1.117)	(1.423)
Observations	4,695	4,695
R-squared	0.172	0.169
F-statistics	48.22	45.76

Significance at 1% (***), 5% (**) and 10% (*). Standard errors in parentheses are robust to arbitrary heteroskedasticity and autocorrelation. The Bartlett kernel with a bandwidth of 2 is used to correct for arbitrary autocorrelation. Specifications (1a) and (1b) represent the first stage of the main estimation of the impact of competition on investment.

Table 3: The impact of regulation on the intensity of competition and the number of firms

	Logarithm of investment						Investment /revenue
	(2)	(3a)	(3b)	(3c)	(4)	(5)	(6)
Competition (1-Lerner)	**46.51*** **	**95.40*** **	**31.17* **	**31.03*** **	**2.64*** **	**67.22*** **	**-41.88*** **
	(13.55)	(18.05)	(18.47)	(11.21)	(0.62)	(13.82)	(8.84)
Squared competition	**-37.01*** **	**-73.20*** **	**-23.56* **	**-22.59*** **	**-1.86*** **	**-50.36*** **	**31.68*** **
	(9.20)	(13.18)	(12.98)	(7.89)	(0.41)	(9.68)	(6.20)
# of entries planned as of Q1 2014						**-0.04** **	
						(0.02)	
Log of working age pop.	0.81***	0.95***	0.75***	0.77***	-0.003	0.87***	0.07***
	(0.03)	(0.29)	(0.05)	(0.07)	(0.002)	(0.04)	(0.02)
Log of pop. density	-0.06**	-0.19***	0.07**	0.02	-0.006***	-0.08***	0.02
	(0.03)	(0.07)	(0.03)	(0.09)	(0.002)	(0.03)	(0.02)
LLU regulation	0.21	-0.05	0.11		-0.016**	-0.00	0.10
	(0.13)	(1.32)	(0.07)		(0.007)	(0.13)	(0.09)
Incumbent FNO	0.17	1.11***	0.25**	-0.11	0.014	0.36**	-0.18**
	(0.13)	(0.41)	(0.13)	(0.16)	(0.009)	(0.14)	(0.09)
Hosting MVNO	0.25**	0.38	-0.10*	0.09	-0.012*	0.13	0.08
	(0.10)	(0.45)	(0.05)	(0.25)	(0.007)	(0.11)	(0.07)
Purchase a license	0.12*	0.69*	0.06	0.32	0.012*	0.18**	0.04
	(0.07)	(0.42)	(0.09)	(0.21)	(0.006)	(0.09)	(0.06)
Quarter	-0.00	-0.04***	-0.01*	0.02***	0.003***	-0.00	-0.01***
	(0.00)	(0.01)	(0.00)	(0.01)	(0.000)	(0.00)	(0.00)
Region fixed effects	√				√	√	√
Constant	-23.70***	-39.73***	-18.36***	-20.08***	2.819***	-31.87***	10.53***
	(4.96)	(10.72)	(7.10)	(3.46)	(0.224)	(4.93)	(3.12)
Observations	4,695	862	1,245	711	3,979	4,695	4,695
Investment maximizing intensity of competition (IMIC):							
Lower bound	0.57	0.54	0.60	0.58	0.66	0.64	0.63
Mean	**0.63**	**0.65**	**0.66**	**0.69**	**0.71**	**0.67**	**0.66**
Upper bound	0.69	0.76	0.73	0.79	0.76	0.70	0.69
Under-identification test (H0: the instruments do not significantly affect the intensity of competition)							
LM statistic	22.25	7.76	7.31	10.67	61.61	24.88	22.25
Weak instruments test (H0: instruments are weak)							
Wald F statistic	12.89	3.71	3.04	5.85	38.72	12.78	12.89

Significance at 1% (***), 5% (**) and 10% (*). Standard errors in parentheses are robust to arbitrary heteroskedasticity and autocorrelation. The Bartlett kernel with a bandwidth of 2 is used to correct for arbitrary autocorrelation.
The confidence interval of the investment maximizing intensity of competition is obtained by computing the standard error based on the delta method.
The Lagrange Multiplier (LM) statistics for under-identification is to be compared to the critical value of a Chi2 with two degrees of freedom at 5% significance level (0.103).
The Weak identification test's Wald F statistics is to be compared to Stock & Yogo (2005)'s critical values: 7.03; 4.58 or 3.95 for a maximal size of 10%, 15% or 20% respectively.

Table 4: The impact of competition intensity on investment in new technologies