What causes the megabyte price drop in the mobile industry?

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Abstract

Mobile industry is characterized by a sharp fall in megabyte price which highly benefits to consumers. This article aims to identify the main parameters that lead to such a fall and shows that the growth of traffic is by far the main cause. It proposes a parametric model that explains the growth of traffic from investment. Using a 20-countries wireless market dataset to calibrate the model, it shows that investment actually drives the exponential growth of traffic. As the growth of revenues are much lower, the price of megabyte decreases sharply. The role of competition is ambiguous. On the one hand it reduces margin and thus prices, on the other hand, as the relationship between investment and competition turns to be inverted-U shaped, it may reduce investment and therefore slow down the fall in unit price.

Keywords: mobile telecommunications, data traffic growth, investment, price of megabyte.

JEL Codes: D24, L96, O31.

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1 Introduction

The price of telecommunications services is a key issue for competition and regulatory authorities. It has a high impact on the whole economy, influencing the growth rate (Röller, 2001; Datta, 2004; Wavermann & Meschi, 2005). To compare the prices of telecommunication services across countries and over time, it seems more appropriate to consider the price of a consumption unit than simply comparing phone plan prices. Indeed, the services offered in a plan can vary widely over time, by country and even between consumers, while consumption units (minute of communication or quantity of data) are much more suited to the comparison. Usage (in minutes or megabytes) characterises better than subscriptions the amount of valuable service provided to users , either as intermediate consumption for business, or as final consumption for households. Today's packages include many more services than a few years ago, though price has not changed in the same proportions. Focusing on plans' costs does not account for this huge growth in usage. The price of a consumption unit uses better reflects market developments.

The unit price of telecommunications services falls sharply over time, which benefits consumers as they significantly increase their consumption. What are the causes of such a fall? Is this the result of increased competition, drastic reduction in operating cost, or rather the effect of technological progress embodied in the network through investment? All these reasons may contribute to lower prices, but not all in the same proportions. To what extent does each of them contribute? This paper attempts to answer this question from both a theoretical and an empirical standpoint. The paper proposes a model that explains the growth of traffic as a function of Investment. It shows that the impact of investment in successive generations of network technologies is predominant in the permanent trend of price reduction of telecommunication services, over time. Static effects like competition and cost reduction are by nature limited. Indeed, competition cannot sustainably decrease the rate of margin under 0% and costs cannot become negative. Dynamic effects, however, are not limited. Cumulative investments always increase traffic and therefore always decrease unit prices. Using a 20 national mobile market dataset provided by Yankee Group and Strategy Analytics from 2006 to 2012, empirical evidence from mobile markets stresses that the impact of competitive intensity and operating costs are almost negligible compared to the impact of investment in a period of just seven years.

The fact that investment is the main driver of unit-price reduction leads to important policy implications. The price cost margin issue is of particular relevance. On the one hand, the current margin has a direct and increasing impact on unit price, on the other hand, the expected margin spurs investment and tends to increase traffic which has a decreasing impact on unit price. Empirical evidence shows that, as expected, the dynamic impact on traffic dominates the static impact on price in the data studied. Empirical evidence also highlights an inverted U relationship between competition and investment that culminates

in an intensity of competition yielding an Ebitda margin rate close to 40% . As a result, strengthened competition resulting in lower margins may accelerate or slow down the decrease in unit-price accordingly as Ebitda margin goes lower or higher than the threshold of 40%. Therefore, competition and regulation authorities should be asking themselves how to invest more rather than how to enhance competition. The intensity of competition should be treated carefully in order to maximize investment and reduce unit prices.

The rest of the paper is organized as follows. The second section is an economic literature review; the third section presents the dataset; the fourth shows that traffic growth is mainly driven by investment. The fifth section explains the evolution of price per Megabyte in relation to margins, costs and traffic growth and concludes that traffic growth totally dominates margin and costs. The sixth section touches on the ambiguous impact of competition and the seventh section is the conclusion and policy implications.

2 Related Literature

Information technologies in general and the telecommunications industry in particular have been experiencing an exponential growth in technological progress for more than a century, according to Koh & Magee, (2006). They highlight a relatively steady annual rate of technical progress in information technologies of around 20% to 30% from the end of the nineteenth century to 2004. The annual rate of technical progress is even higher between 1940 and 2004, around 25 to 40%, high above that of the energy sector's 6% (Koh & Magee, 2008). In particular, Koh and Magee highlight an exponential growth of performances for a given amount spent. For example, in data storage, the number of megabits stored per USD, or in data transportation, the number of Kbits per second per Km per USD.

This high technical progress spurs investment. Doms highlights that the sharp increase in telecommunication service providers' investments, in the late 1990s corresponds to an acceleration of the technical progress rate (Doms, 2004). Technical progress generates opportunities to improve the quality of service for consumers and encourages telecom operators to invest (Jeanjean, 2011).

Thanks to technological progress and investment, wireless industry data traffic has been experiencing exponential growth for several years (Cisco Networking Index). Such growth, underscored by Price (Price, 1963) has been widely observed in information technologies (Moore's law) and even in other sectors (Tague, J., Beheshti, J., & Rees-Potter, L., 1981), (Schummer, 1997).

Chapin & Lehr (2011) also note this growth in traffic. They indicate that it may lead to an increase in infrastructure costs and a shortage of spectrum. They are concerned about the harmful impact that this could have on competition. To cope with this problem, they suggest infrastructure and spectrum sharing. In its report "Supercollider" HSBC suggests market consolidation rather than network sharing. HSBC argues that network sharing is a complement but not an

alternative to consolidation. Network sharing reduces costs whereas consolidation, to a certain extent, supports heavier investment in infrastructure (HSBC, 2014).

Many papers acknowledge the role of investment in the growth of traffic; however, to my knowledge, none explains how investment generates traffic.

Competition has an ambiguous impact on investment incentives. On the one hand, competition encourages investment with the "escape competition effect" mentioned by Arrow,(1962), and on the other hand, it deters investment reducing future expected profits. Shumpeter,(1942) pointing out that incentives to invest are higher in a monopoly than in a competitive market. Gilbert & Newbery, (1982) underlined that a monopoly firm has more incentive to invest in innovation than a potential entrant firm. As a result, there seems to be an inverted U relationship between competition and investment in the telecommunications industry. This relationship highlighted by Aghion, Bloom, Blundell, & griffith, (2005) between competition and innovation has been extended between competition and investment in several empirical studies (Friederiszick, Grajek, & Röller, 2008; Kim, Kim, Gaston, Lestage, & Kim & Flacher, 2011); (Houngbonon & Jeanjean 2014).

3 Data set

The dataset combines annual financial information from 20 countries around the world between 2006 and 2012.

Total revenues, Capex (the funds used by a company to acquire or upgrade physical assets such as property, industrial buildings or equipment) and Ebitda per country in millions of USD are provided by Yankee group mobile Carrier Monitor. Four reports have been used according to countries' world zone, "EMEA Mobile Carrier Monitor", "North America Mobile Carrier Monitor", "Latin America Mobile Carrier Monitor" and "Asia-Pacific Mobile Carrier Monitor". In the rest of the paper, Ebitda is treated as profit and Capex as Investment.

Traffic per country in Petabytes is provided by Strategy Analytics on an annual basis. As it is not possible to measure all traffic, information from Strategy Analytics reports are estimated values. In order to estimate traffic, Strategy Analytics multiply the number of events with the average size of each type of event. The events are for example video, games, music,... The number and average size of events are input information. Strategy analytics update its model regularly with current input data. The report used in the paper was updated in 2013 using 2012's information. Until 2012, input data is current data. After 2012, input data is forecasted data. This paper does not use data from after 2012. Therefore all the data used is estimated data from actual inputs. Our purpose is to explain the relationship between investment and data traffic. To do so, we need the total traffic handled on the mobile infrastructure in each country, irrespective of traffic type: tablet, PC, Handset and even voice

traffic because voice traffic, regardless of whether it uses 2G, 3G or LTE, is part of the customer experience and consumes network resources and hence investment. As voice is counted in minutes, it is necessary to convert minutes into data bytes to be added to other types of traffic. Total traffic is the sum of Handset data traffic, PC/Modem data Traffic, Tablets data Traffic and Voice traffic. Handset traffic is provided by The "Global Mobile Media Forecast; Handset Data Traffic (2001-2017)" file, Tablets data traffic is provided by the "Global Active Mobile Broadband Tablet Subscription Forecast: 2010-2017" file, PC/Modem data traffic is provided by the "Global Active Mobile Broadband PC/Modem Subscription Forecast: 2007-2017" file and voice traffic is estimated based on the number of voice minutes. It is assumed that one minute of voice represents 95 Kbytes. This is the case using an Adaptive Multi-Rate Wideband AMR-WB (G.722.2) that codes the voice at a 12.65 Kbits/s rate. This is not the only rate used, however, but an average rate providing good quality. The number of voice minutes as well as the number of users per country are provided by the "Worldwide Cellular User Forecasts, 2013-2018".

Voice in this paper is considered as an application like any other (messaging, browsing, video, games,...). The variables of interest are not the applications themselves but the resources they consume in the network in terms of traffic. Moreover, in the network, the difference between voice and data tends to vanish. In LTE, voice is transferred via IP protocol just like data.

The number of users seems more relevant than the number of subscribers because the number of plans per user highly varies by country. The table below (Table.1) represents the descriptive statistics for the whole sample of 20 countries.

20 countries	Revenues	Ebitda	Capex	Traffic	Users	ARPU	Traffic/User	Price/Mbyte
	US$ (millions)	US$ (millions)	US$ (millions)	Petabyte	millions	US$	Mbyte	US$
2006	487 514	194 235	95 319	580	1390	351	417	0,84
2007	568 230	214 544	102 016	843	1571	362	536	0,67
2008	574 545	242 699	106 042	1290	1740	330	741	0,45
2009	627 545	244 457	104 175	2071	1921	327	1078	0,30
2010	662 736	262 986	113 502	3624	2107	315	1720	0,18
2011	690 893	275 881	119 548	6071	2261	306	2685	0,11
2012	716 914	276 268	142 149	9461	2391	300	3958	0,08
CAGR	**6,64%**	**6,05%**	**6,89%**	**59,25%**	**9,46%**	**-2,58%**	**45,48%**	**-33,04%**

Table.1: Descriptive Statistics (Global)

In all the countries, during the studied period, traffic increases exponentially, while the variations in the other variables are much more moderate. As a result, the average revenue per megabyte (price/Mbyte) decreases sharply. Growth of revenues, Ebitda and Capex are mainly driven by the growth of users. Revenues, Ebitda and Capex per user slightly decreased over the period while Traffic per user increased exponentially. In only 6 years, consumers enjoyed a 10-fold increase in traffic for a nearly constant price. This trend is common to all countries. The table below (Table.1bis) describes the evolution in terms of Compounded Annual Growth rate (CAGR) for each country.

Country	Revenues	Ebitda	Capex	Traffic	Users	ARPU	Traffic/User	Price/Mbyte
South Africa	7,63%	6,45%	1,68%	61,85%	6,30%	1,25%	52,26%	-33,50%
Argentina	13,18%	20,25%	10,05%	56,56%	4,94%	7,85%	49,19%	-27,71%
Brazil	13,77%	22,82%	10,43%	71,51%	10,38%	3,08%	55,38%	-33,66%
Mexico	5,67%	3,95%	8,26%	59,11%	10,50%	-4,37%	44,00%	-33,59%
Australia	14,42%	18,92%	15,53%	88,18%	1,96%	12,22%	84,56%	-39,20%
China	16,05%	9,24%	20,01%	49,93%	16,01%	0,03%	29,24%	-22,60%
India	23,30%	22,39%	-5,38%	46,89%	20,53%	2,30%	21,87%	-16,06%
Japan	5,34%	7,38%	5,70%	85,07%	2,56%	2,71%	80,46%	-43,08%
Korea	0,62%	3,52%	13,42%	64,36%	1,24%	-0,61%	62,34%	-38,78%
Czech Republic	0,32%	1,29%	2,61%	56,72%	0,92%	-0,59%	55,30%	-35,99%
Poland	0,68%	-0,62%	-0,93%	60,18%	1,71%	-1,01%	57,49%	-37,15%
Russia	12,99%	10,88%	15,11%	73,59%	2,68%	10,04%	69,07%	-34,91%
France	1,25%	-2,35%	-4,92%	55,97%	3,05%	-1,75%	51,35%	-35,08%
Germany	-0,83%	0,09%	-6,71%	71,66%	0,98%	-1,80%	69,99%	-42,23%
Italy	-3,52%	-4,18%	-6,81%	68,02%	1,23%	-4,69%	65,97%	-42,58%
Spain	-3,95%	-5,80%	-6,26%	61,23%	1,49%	-5,36%	58,86%	-40,43%
Sweden	6,70%	7,25%	13,44%	93,23%	1,54%	5,09%	90,31%	-44,78%
UK	-3,11%	-5,66%	-1,66%	71,34%	1,55%	-4,58%	68,73%	-43,45%
Canada	10,87%	6,70%	12,47%	70,76%	6,17%	4,43%	60,84%	-35,07%
USA	6,69%	6,82%	1,84%	54,74%	4,86%	1,74%	47,57%	-31,05%

Table.1bis: Evolution 2006-2012 per country

In all countries, the growth of Traffic is much higher than the growth of Revenues; even in the emerging countries where growth in the number of users is fairly high, like India and China and to a lesser extent Brazil and Mexico.

4 Traffic is driven by investment

One wonders what is driving this growth. Investment by mobile operators or the increasing use of consumers over time, driven by experience and imitation? Obviously, both are necessary. Investment is necessary to install the capacity required to handle the traffic and consumer demand is necessary to increase traffic. What is the relative importance of time and investment in traffic growth? This question is even more difficult because the investment is relatively stable over time, making the cumulative investment strongly correlated with time. However as Romer said, "*no economist, so far as I know, has ever been willing to make a serious defence of the proposition that technological change is literally a function of elapsed calendar time*" (Romer P. 1994).

In order to disentangle this problem, let us consider a basic model that represents investment in the infrastructures of telecommunication. Telecommunications operators invest in infrastructure equipment in order to be able to handle traffic while providing decent service quality. New generation equipment is generally developed and commercialized by equipment providers, no telco themselves. This is the reason why, in this model, it is assumed that technical progress is regular and exogenous. Indeed, technical progress is not significantly affected by operators' investment made at a national level because the equipment manufacturers who manage the innovation process of equipment

have an international dimension. Hence telecom equipment is available to all operators around the world simultaneously and technical progress appears exogenous from the operators' point of view. The regularity of technical progress leads to a constant technical progress rate per unit of time, θ.This is a simplification. As explained Christensen (1992), technological performance curves are S-shaped and therefore the rate of technical progress is not constant. However, the different generations of technology are intertwined so that the rate of technical progress, by choosing the most efficient technology, is much more stable. A constant (or almost constant) progress rate is a common feature in information technologies as highlighted by Koh and Magee (2006). Moore's law also exhibits a constant progress rate as well as the Cisco Networking index and the Ericsson Mobility report concerning data traffic growth.

At a given point of time, t, the level of technological knowledge in telecommunication infrastructure is measured by A_t, where A_t represents the capacity that the level of knowledge allows to build into the network per unit of money. Technological progress improves processes and reduces production costs allowing the industry to offer more for the same price. The technical progress rate represents the rate of growth of capacity built into the network at constant price and measures the industry's ability to improve its performances. The cost of building capacity in the network includes not only the cost of network equipment (antennae, radio transmitters, switches, routers, multiplexers...) but also non-network facilities (Spectrum licenses,buildings, technical environment, miscellaneous supplies). Despite the international dimension of equipment manufacturers, countries are not all at the same level of development. Each country uses its own technology mix combining together different generations of equipment (2G,3G,LTE...). This mix of technology evolves with technical progress. Firstly, the proportion of latest generation equipment tends to increase at the expense of the oldest, and secondly, the price of the older generation tends to decrease. Ultimately, the capacity purchased for a unit of money, increases over time regardless of the technology mix. However, the pace of technological progress may depend on the technology mix, which explains in part differences in rates of technical progress among countries.

At time $t+1$, the level of technical knowledge becomes $A_{t+1} = A_t(1+\theta)$.At the origin of time, the initial level of knowledge is A_0. Thus, the level of knowledge at time t is written $A_t = A_0(1+\theta)^t$.Such an evolution in performance at constant prices is reflected in the work of Koh and Magee (2006), especially for information technologies.

Investment allows you to incorporate technical progress into the infrastructure. At time t, an amount of investment I_t lets you add new capacity, $A_t.I_t$ in the network according to the level of knowledge. However, the oldest equipment in the network becomes obsolete and is removed. Let us assume that the equipment lifetime is, δ, at time t, with all the equipment installed at time $t-\delta$ being removed. Network capacity variation at time t is written $\Gamma_t - \Gamma_{t-1} = A_t I_t - A_{t-\delta} I_{t-\delta}$ for $t \geq \delta$ and $\Gamma_t - \Gamma_{t-1} = A_t I_t$ otherwise. Indeed, when $t \leq \delta$, there is no obsolete equipment.

At $t=0$, it is assumed that $\Gamma_0 = A_0 I_0$. At time t, the accumulation and the

removal of equipment bring about the capacity:

$$\Gamma_t = A_0 \left[\sum_{i=0}^{t} (1+\theta)^i I_i - \sum_{i=\delta}^{t} (1+\theta)^{i-\delta} I_{i-\delta} \right] \quad (1)$$

The traffic handled in the infrastructure can be deduced from the capacity with the occupancy rate, α. the traffic is written $T_t = \alpha\Gamma_t$. In order to allow a good quality of service and to avoid network congestion, the occupancy rate needs to be sufficiently low. However, in order to optimize investment, the occupancy rate needs to be sufficiently high. As a result, the occupancy rate must remain within a relatively narrow range. Network design rules, following Erlang's formulae set out this narrow range. Indeed, Erlang's internet formula (derived from Erlang's C formula) used for data protocols like IP, as indicated by Bonald and Robert (2012) shows that when traffic approaches full capacity, congestion increases very sharply, so that a little delay in investment may considerably impact the quality of service (see Annex 8.5). In the following, for the sake of simplicity, we assume that the occupancy rate of the infrastructure remains constant over time.

Variations in investment over time in each country can be approximated by the Compound Annual Growth rate during the period $t_0 = 2006$ and $t_f = 2012$, $\lambda = (I_{t_f}/I_{t_0})^{\left(\frac{1}{t_f - t_0}\right)} - 1$, such that for each country at time t, Investment is written: $I_t = I_{t_0}(1+\lambda)^{t-t_0} + \mu_t$. μ_t is the difference between actual investment and the approximation: $I_{t_0}(1+\lambda)^{t-t_0}$. It is noteworthy that $\mu_{t_0} = \mu_{t_f} = 0$, because $I_{t_0} = I_{t_0} + \mu_{t_0}$ and $I_{t_f} = I_{t_f} + \mu_{t_f}$. This provides a good approximation of investment. The graph below represents for all countries the difference between actual Investment and approximation.

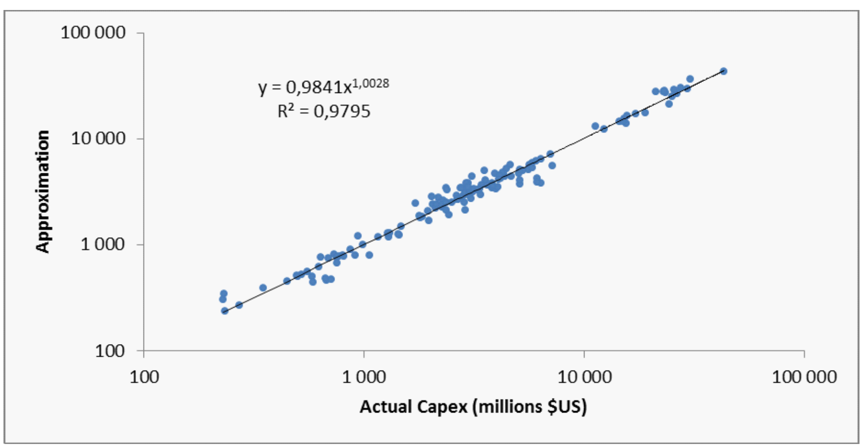


Figure.1: Approximation of Capex

The average difference between actual investment and approximation is under 11.3 %. The distribution of the relative difference, for $t \in [t_0, t_f]$, $\frac{\mu_t}{I_t}$,

according to both the Shapiro-wilk and the Kolmogorov-Smirnov tests, can be considered as a standard normal distribution with a 0.195 standard deviation (see annex 8.2). Therefore, μ_t is considered as a random error term. For simplification, in equation (1), I_t is replaced by its approximation: $I_{t_0}(1+\lambda)^{t_f - t_0}$. As $E(\mu_t/t) = 0$, the approximation does not change the value of $E(T_t/t)$ and does not impact the estimation of T_t. By defining $\left(1+\theta'\right) = (1+\theta)(1+\lambda)$, traffic at time t is written (see proof in annex 8.1):

$$T_t = T_{t_0}\left(1+\theta'\right)^{t-t_0} \tag{2}$$

If this expression is a good approximation of the growth of traffic in each country, it shall enable us to estimate the level of technical progress.

For each country, we consider the following equation:

$$\ln\left(\frac{T_t}{T_{t_0}}\right) = (t-t_0)\ln\left(1+\theta'\right) + \varepsilon_t \tag{3}$$

with ε_t, the error term such that $\varepsilon_t = f(\mu_t) + \varepsilon'_t$. $f(\mu_t)$ is the share of error term due to the approximation on the growth in investment and ε'_t is the share of error term due to other unknown factors. As $\frac{\mu_t}{I_t}$, distribution of ε_t can be considered as a standard normal distribution(see annex 8.2).

t_0 represents the year 2006, and t takes all the values from 2006 to 2012, giving 7 observations per country. The estimation of θ' for each country is obtained with the OLS. At time t_0, $T_t = T_{t_0}$, thus there is no constant term. The following table, (Table.2) reports the results for each country.

Countries	θ'	t statistic	R²	λ	θ	95% confidence interval	
						min	max
South Africa	59%	65,41	0,999	2%	57%	54%	60%
Argentina	54%	27,85	0,992	10%	40%	35%	45%
Brazil	75%	25,26	0,991	10%	58%	50%	67%
Mexico	56%	53,85	0,998	8%	44%	42%	47%
Australia	102%	20,96	0,987	16%	75%	61%	90%
China	46%	21,91	0,988	20%	21%	16%	27%
India	50%	31,77	0,994	-5%	59%	54%	64%
Japan	88%	97,50	0,999	6%	78%	75%	81%
Korea	66%	91,46	0,999	13%	46%	44%	48%
Czech Republic	63%	21,93	0,988	3%	59%	51%	68%
Poland	64%	51,90	0,998	-1%	66%	62%	70%
Russia	78%	24,30	0,990	15%	55%	46%	64%
France	48%	14,61	0,973	-5%	56%	46%	66%
Germany	72%	73,50	0,999	-7%	84%	81%	87%
Italy	71%	53,79	0,998	-7%	84%	79%	88%
Spain	62%	59,86	0,998	-6%	72%	69%	76%
Sweden	107%	24,48	0,990	13%	83%	70%	96%
UK	74%	52,42	0,998	-2%	77%	73%	82%
Canada	64%	18,80	0,983	12%	46%	37%	55%
USA	51%	29,56	0,993	2%	48%	43%	53%

Table.2: Estimation of Annual Technical Progress Rate θ

Even with a low number of observations, the model fits quite well with observations with $R^2 > 0.97$ in all countries and $R^2 > 0.99$ in most countries. This model of traffic growth can be used to calculate the evolution of the price per megabyte.

5 The price of the megabyte

Unit price, up, may be expressed as the ratio between Revenue, R, and traffic, T: $up = \frac{R}{T}$. Unit price is thus inversely proportional to the traffic. The relationship between Ebitda, E, operating costs, C, and revenues is written: $E = R - C$, the Lerner index L is defined by $L = \frac{E}{R}$. As a result, the Revenue is: $R = \frac{C}{1-L}$, where L represents a proxy of the market power and $(1 - L)$ is highly correlated to the price competition intensity. Competition intensity tends to decrease L, and thus to increase $(1 - L)$ which is a common proxy for competition intensity used inter alia by Aghion et al (2005). Equation (2) provides the expression of traffic growth:

$T_t = T_{t_0}\left(1+\theta'\right)^{t-t_0}$. Therefore, unit price is written:

$$up = \frac{C\left(1+\theta'\right)^{-(t-t_0)}}{T_{t_0}(1-L)} \tag{4}$$

The contribution of each variable to the unit price change is driven by the elasticities:

$$\begin{aligned}
\eta_C &= \frac{\partial up}{\partial C}\frac{C}{up} = 1 \qquad (5)\\
\eta_{(1-L)} &= \frac{\partial up}{\partial (1-L)}\frac{(1-L)}{up} = -1\\
\eta_{t-t_0} &= \frac{\partial up}{\partial (t-t_0)}\frac{t-t_0}{up} = -\left(t-t_0\right)\ln(1+\theta')
\end{aligned}$$

It is possible to express η_{t-t_0} according to the technical progress rate θ and the CAGR of Capex, λ :

$\eta_{t-t_0} = \eta_\theta + \eta_\lambda$ with $\eta_\theta = -(t - t_0)\ln(1 + \theta)$ and $\eta_\lambda = -(t - t_0)\ln(1 + \lambda)$. η_λ represents the elasticity of unit price according to variations in investment. When Investment increases, λ is positive and $\eta_\lambda$is negative which means that Investment has a decreasing impact on unit prices. In the same manner, technical progress has a decreasing impact on unit price. However, in this model, the possible impact of investment on technical progress is not studied since technical progress is exogenous and supposed to be constant in each country during the period under study. Notice that η_θ also depends on Investment. It depends on the steady part of Investment I_{t_0}

It is noteworthy that the elasticities of operating costs and competition are constant while the elasticity of investment η_{t-t_0}depends negatively on time with

an increasing absolute value. This means that the impact of operating costs and competition on unit price are static while impact of investment is dynamic.

The sign of the elasticity of operating costs is positive. An increase in operating costs, all things held equal increases the unit price. The sign of the elasticity of competition is negative. An increase in competition intensity, all things held equal, reduces the Ebitda margin and then the unit price. The sign of Investment elasticity is negative because investment increases traffic which reduces unit price.

The impacts of operating costs and competition are static. Their elasticities remain equal to unity. The impacts of investment are dynamic, they increase over time. As a consequence, the impact of dynamic effects becomes predominant after a while. Moreover, operating costs and competition can increase or decrease over time while cumulative investment always increases. Specifically, the dynamic effects outweigh the static effects after only a few months. On the entire 7-year period between 2006 and 2012, the static effects appear almost negligible compared to the dynamic effects.

Using the dataset, it is possible to determine the actual contribution of each parameter to the fall in unit price during the period 2006-2012. $t_0 = 2006$ and $t_f = 2012$ After some transformations (see annex 8.3), equation (4) yields:

$$\ln\left(\frac{up_{t_f}}{up_{t_0}}\right) = \ln\left(\frac{C_{t_f}}{C_{t_0}}\right) - \ln\left(\frac{(1-L)_{t_f}}{(1-L)_{t_0}}\right) - 6\ln(1+\theta) - 6\ln(1+\lambda) \qquad (6)$$

The value of each term represents the relative change of one parameter during 2006 and 2012. The following table, (Table.3) provides country-by-country results:

Country	**ln(Uptf/Upto)**	**-Ln(Ctf/Cto)**	**-ln(1-Ltf)/(1-Lto)**	**-6ln(1+θ)**	**-6ln(1+λ)**	Σ
South Africa	**-2,45**	0,48	-0,04	-2,70	-0,10	**-2,36**
Argentina	**-1,95**	0,58	0,16	-2,01	-0,57	**-1,84**
Brazil	**-2,46**	0,58	0,20	-2,75	-0,60	**-2,58**
Mexico	**-2,46**	0,43	-0,09	-2,21	-0,48	**-2,35**
Australia	**-2,99**	0,64	0,17	-3,35	-0,87	**-3,41**
China	**-1,54**	1,56	-0,67	-1,16	-1,09	**-1,36**
India	**-1,05**	1,27	-0,01	-2,78	0,33	**-1,19**
Japan	**-3,38**	0,26	0,05	-3,47	-0,33	**-3,49**
Korea	**-2,94**	-0,07	0,10	-2,29	-0,76	**-3,01**
Czech Republic	**-2,68**	-0,03	0,05	-2,79	-0,15	**-2,93**
Poland	**-2,79**	0,07	-0,03	-3,03	0,06	**-2,94**
Russia	**-2,58**	0,81	-0,08	-2,62	-0,84	**-2,73**
France	**-2,59**	0,17	-0,09	-2,66	0,30	**-2,28**
Germany	**-3,29**	-0,09	0,04	-3,66	0,42	**-3,29**
Italy	**-3,33**	-0,17	-0,04	-3,65	0,42	**-3,44**
Spain	**-3,11**	-0,17	-0,07	-3,27	0,39	**-3,12**
Sweden	**-3,56**	0,37	0,02	-3,61	-0,76	**-3,98**
UK	**-3,42**	-0,14	-0,05	-3,44	0,10	**-3,53**
Canada	**-2,59**	0,81	-0,19	-2,25	-0,71	**-2,34**
USA	**-2,23**	0,38	0,00	-2,36	-0,11	**-2,09**

Table.3: Contribution to the fall in megabyte price

The model's prediction after 7 years (column Σ) is close to the observed changes in megabyte price (column $\ln\left(\frac{up_{2012}}{up_{2006}}\right)$). The fit between prediction and observed values creates an R^2 of 0.94.

The growth of the number of users affects the growth of operating costs as well as Traffic especially in developing countries. It seems relevant to use per user figures in addition to total figures. Without changing the result, it is possible to express the price of Megabyte according to the operating costs per user and the Traffic per user: $up = \frac{C/U}{(1-L)T/U}$

From year t_0 and year t_f, static effect, Se, is composed of operating cost and competition intensity such that: $\ln\left(\frac{Se_{tf}}{Se_{t_0}}\right) = \ln\left(\frac{C_{tf}}{C_{t_0}}\right) - \ln\left(\frac{(1-L)_{tf}}{(1-L)_{t_0}}\right)$ and dynamic effect, De, is composed of the impact of the growth of traffic such that: $\ln\left(\frac{De_{tf}}{De_{t_0}}\right) = -\left(t_f - t_0\right)\left[\ln\left(1+\theta\right) + \ln(1+\lambda)\right]$.

Similarly, Static effect per user, $Sepu$, is written: $\ln\left(\frac{Sepu_{tf}}{Sepu_{t_0}}\right) = \ln\left(\frac{C_{tf}}{C_{t_0}}\right) - \ln\left(\frac{(1-L)_{tf}}{(1-L)_{t_0}}\right) - \ln\left(\frac{U_{tf}}{U_{t_0}}\right)$ and Dynamic effect per user, $Depu$,: $\ln\left(\frac{Depu_{tf}}{Depu_{t_0}}\right) = -\left(t_f - t_0\right)\left[\ln\left(1+\theta\right) + \ln(1+\lambda)\right] + \ln\left(\frac{U_{tf}}{U_{t_0}}\right)$Total impact on unit price can be written: $\ln\left(\frac{up_{tf}}{up_{t_0}}\right) = \ln\left(\frac{Se_{tf}}{Se_{t_0}}\right) + \ln\left(\frac{De_{tf}}{De_{t_0}}\right) = \ln\left(\frac{Sepu_{tf}}{Sepu_{t_0}}\right) + \ln\left(\frac{Depu_{tf}}{Depu_{t_0}}\right)$.Growth of users decreases static effect and increases (decreases in absolute value) dynamic effect by the same value, and consequently does not change unit price.

The Compounded Annual Growth Rate (CAGR) of the change in megabyte price is $CAGR_{up(t_f - t_0)} = \left(\frac{up_{tf}}{up_{t_0}}\right)^{\frac{1}{t_f - t_0}} - 1 = e^{\frac{1}{(t_f - t_0)}\ln\left(\frac{up_{tf}}{up_{t_0}}\right)} - 1$.

Similarly, for an effect of the sort $X \in \{Se, Sepu, De, Depu\}$, the contribution in terms of Compounded Annual Growth Rate (CAGR) to the change in megabyte price is: $CAGR_{X(t_f - t_0)} = e^{\frac{1}{(t_f - t_0)}\ln\left(\frac{X_{tf}}{X_{t_0}}\right)} - 1$. For the whole period $t_f = 2012$ and $t_0 = 2006$.

The following table, Table.3bis, provides the contributions to the change in unit price in Compounded Annual Growth Rate.

Country	Static	Dynamic	Static (per user)	Dynamic (per user)	Total	Unit price
South Africa	8%	-37%	1%	-33%	**-33%**	**-34%**
Argentina	13%	-35%	8%	-32%	**-26%**	**-28%**
Brazil	14%	-43%	3%	-37%	**-35%**	**-34%**
Mexico	6%	-36%	-4%	-29%	**-32%**	**-34%**
Australia	14%	-50%	12%	-50%	**-43%**	**-39%**
China	16%	-31%	0%	-20%	**-20%**	**-23%**
India	23%	-34%	2%	-20%	**-18%**	**-16%**
Japan	5%	-47%	3%	-46%	**-44%**	**-43%**
Korea	1%	-40%	-1%	-39%	**-39%**	**-39%**
Czech Republic	0%	-39%	-1%	-38%	**-39%**	**-36%**
Poland	1%	-39%	-1%	-38%	**-39%**	**-37%**
Russia	13%	-44%	10%	-42%	**-37%**	**-35%**
France	1%	-33%	-2%	-31%	**-32%**	**-35%**
Germany	-1%	-42%	-2%	-41%	**-42%**	**-42%**
Italy	-4%	-42%	-5%	-41%	**-44%**	**-43%**
Spain	-4%	-38%	-5%	-37%	**-41%**	**-40%**
Sweden	7%	-52%	5%	-51%	**-48%**	**-45%**
UK	-3%	-43%	-5%	-42%	**-44%**	**-43%**
Canada	11%	-39%	4%	-35%	**-32%**	**-35%**
USA	7%	-34%	2%	-31%	**-29%**	**-31%**

Table 3bis: Static and dynamic effect (CAGR)

The "Total" column represents the cumulation of static and dynamic effects. In CAGR the cumulation is calculated following: $CAGR_{Total} = (1 + CAGR_{Dynamic})(1 + CAGR_{Static}) - 1$. Negative signs mean a decreasing contribution to the megabyte price and positive signs mean an increasing contribution. According to the theoretical model, Total might represent the CAGR of unit price. Empirically, the adjustment between Total and Unit price CAGR columns is $R^2 = 0.943$ which means that the model provided by equation (4) fits quite well with observations. Contributions of static effects (operating costs and competition) are relatively low compared to contributions of dynamic effects. In the case of South Africa, for example (first line), static effects have entailed a yearly increase of 8% for megabyte price, while dynamic effects entailed a decrease by 37%. Static (per user) effects increased unit price by 1% while dynamic (per user effect) decreased it by 33%. The graph below (figure.2) compares the contributions of static and dynamic effects to the fall in megabyte price.

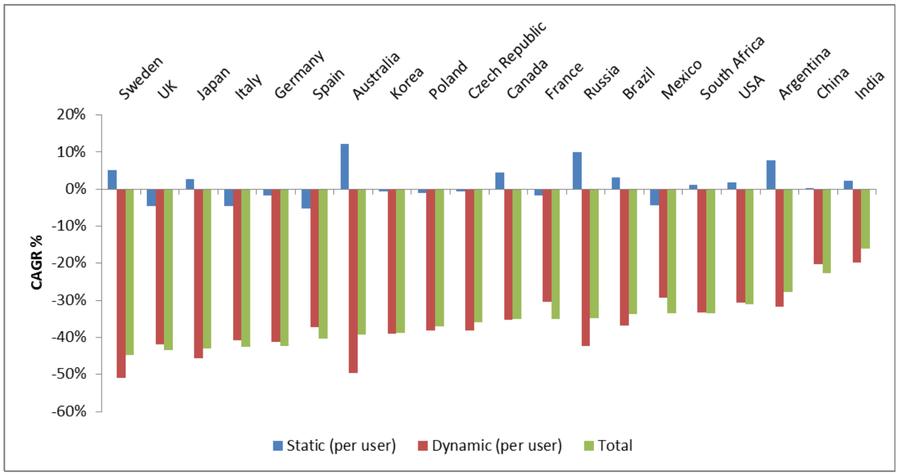


Figure.2: Contributions to the fall in Megabyte price (CAGR 2006-2012)

The contribution of static effects may be positive or negative. Indeed, during the period 2006-2012, competitive intensity increased in some countries and decreased in others. Same for operating costs (see Table.3). While static effects can increase or decrease unit prices, dynamic effects always contribute to decrease them. During the period 2006-2012, dynamic effects have had a much greater impact than static effects, and this difference increases over time. Indeed, the elasticities of dynamic effects increase over time while elasticities of static effects remain steady (see equation 5). Moreover, the potential for change of static effects are limited; indeed, it is not possible to increase competition intensity beyond perfect competition $(1 - L) = 1$, operating costs cannot sustainably exceed revenues, revenue per user cannot exceed consumers' willingness to pay and the number of users (different from subscribers) cannot exceed the population while cumulated investment regularly increases. Even if investment could have an impact on competition, what is not significantly found (coefficient of correlation between λ and CAGR of $1 - L$ is 0.02), its impact remains bounded and does not compensate for the dynamic impact on the growth of traffic.This is the reason why, in the long run, static effects become negligible compared to dynamic effects.

6 In the wireless industry, fierce competition may slow down the decrease in megabyte price.

Fierce competition reduces Ebitda margin. If reduced margins increase investment, then static and dynamic effects pull in the same direction and tend to decrease megabyte price. However, if reduced margins decrease investment, then

static and dynamic effects pull in the opposite direction. In that case, since the dynamic effect outweighs the static effect, the overall effect should slow down the decline in unit price.

This section empirically highlights that the relationship between competition and investment turns into an inverted-U shape, in the wireless industry. It is found that the slope of Investment growth rate (Capex) as a function of the intensity of competition measured as (1-L) is significantly and negatively correlated to the average intensity of competition during the period 2006-2012. The slope is positive for countries with low intensity of competition and becomes negative for the countries with high intensity of competition. This suggests that Investment tends to increase with the intensity of competition when competition is weak and to decrease when it is fierce. As a result, this suggests an inverted-U relationship between competition and Investment. The intensity of competition at which the slope is flat is close to 60%. This corresponds to the intensity of competition which maximizes investment.

The rate of growth of investment at time t is defined by $\rho_t = \frac{I_t - I_{t_0}}{I_{t_0}}$. The growth rate slope as a function of the intensity of competition is: $\frac{\sum_{i=t_0}^{t}(\rho_t-\overline{\rho})\left((1-L)_t-\overline{(1-L)}\right)}{\sum_{i=t_0}^{t}(\rho_t-\overline{\rho})^2}$ with $\overline{\rho} = \frac{1}{t-t_0+1}\sum_{i=t_0}^{t}\rho_i$ and $\overline{1-L} = \frac{1}{t-t_0+1}\sum_{i=t_0}^{t}(1-L)_i$. For each country, the slope is calculated for the whole period $t_0 = 2006$ and $t_f = 2012$.

The figure below, Figure.3, represents the relationship between the investment growth rate slope as a function of the intensity of competition.

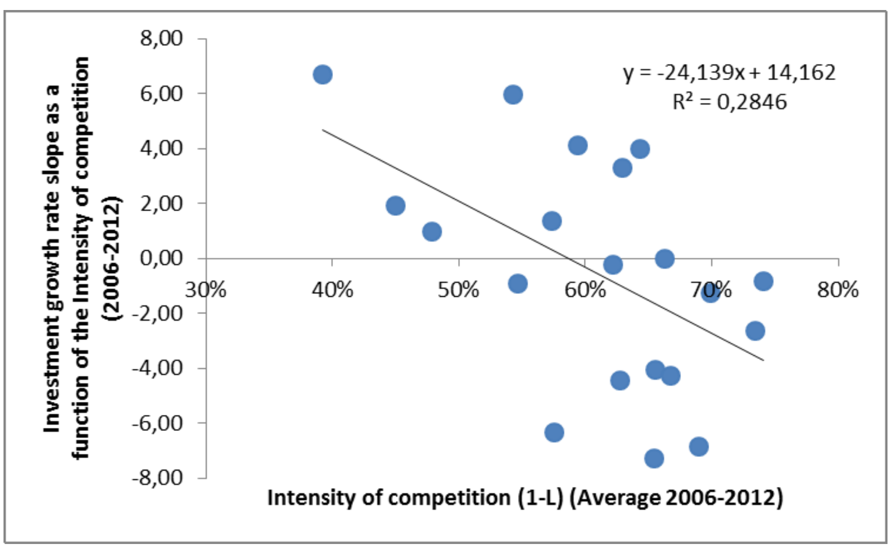


Figure 3: Relationship between competition and investment

Countries whose intensity of competition has tended to move away from 60% (increasing or decreasing) also tended to reduce their investment and therefore slow down the fall in megabyte price. By contrast, countries whose intensity of competition has tended to get closer to 60% (increasing or decreasing) tended to increase investment and accelerate the fall in megabyte price. The graph below, Figure.4, shows the contribution of the change in competition intensity to the megabyte price evolution.

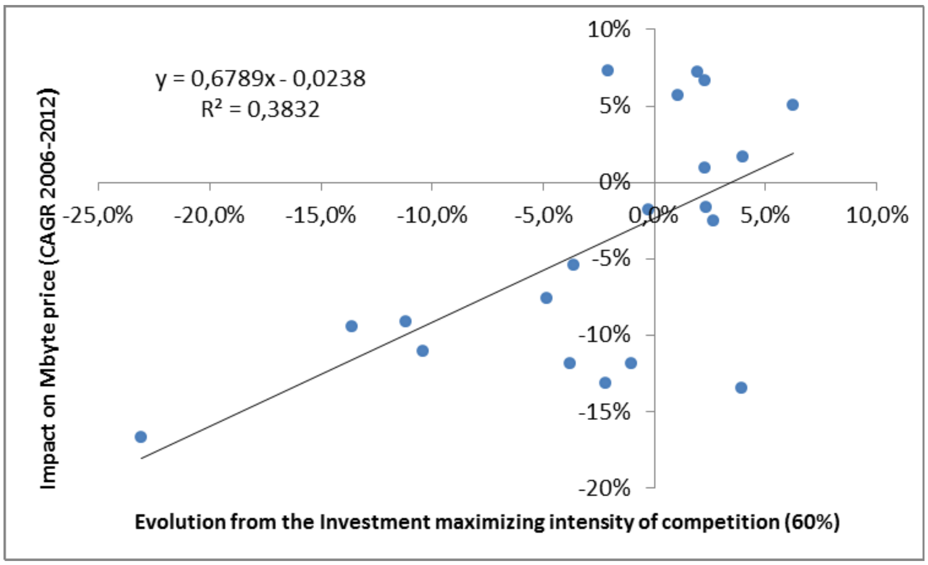


Figure.4: Impact of the evolution of the intensity of competition on Megabyte price

In figure 4, x-axis is defined by: $|(1-L)_{2012} - 60\%| - |(1-L)_{2006} - 60\%|$, and the y-axis by $\frac{-\lambda}{1+\lambda}$ (see annex 8.4). The positive values on the x-axis correspond to a movement away from the intensity of competition that maximizes Investment (1-L = 60%), and the negative values correspond to a convergence toward the maximizing level. The positive values on the y-axis correspond to a slow down of the fall in Megabyte price and the negative values correspond to an acceleration of the fall in Megabyte price.

Countries where the intensity of competition moves away from 60% tend to slow down the fall in megabyte price. Those where the intensity of competition get closer to 60% tend to accelerate it. This is because moving away reduces investment while coming closer increases it.

As a result, strengthening competition in countries where $1-L < 60\%$ helps accelerate the fall in megabyte price by both static and dynamic effects working in the same direction. By contrast, strengthening competition in countries where $1-L > 60\%$ may slow down the fall in unit price because in this case, static and dynamic effects work in opposite directions. Static effect accelerates the

fall in price while dynamic effect slows it down. But dynamic effect, in the long run, tends to become predominant. Hence, finally, enhanced competition in this case tends to slow down the fall in megabyte price.

7 Conclusion

In a highly innovative industry, like telecommunication and particularly the wireless industry, where technical progress is tremendous, investment becomes the key issue. Investment drives the growth of traffic in an exponential relationship, while competition avoids such a growth of subscription price. Competition tends to decrease price cost margins, however, even perfect competition cannot bring down the price below marginal costs, and marginal costs cannot be negative. As a result, static effects as competition and cost reduction are limited. Dynamic effects, mainly driven by cumulative investment, on the contrary, continuously and exponentially increase traffic. There is theoretically no limit, and in practice, consumers demand has not reached the point of satiety. Traffic increases much faster than revenues, as a result, price of megabyte decreases sharply allowing consumers to benefit from a higher bit rate for a pretty steady price. This traffic growth also benefits to service and content providers who take the opportunity to improve their offer.

However, investment requires some margin, the impact of which differs according to its position with respect to the investment maximizing level of margin. Below this level, an increase in the margin has two effects. In the short run, it reduces consumer surplus by increasing subscription price. In the long run, it raises consumer surplus by increasing investment and traffic which accelerates the fall in megabyte price. Above the investment maximizing level of margin, a further increase in the margin reduces investment and consequently, reduces consumer surplus both in the short and in the long run.

Competition and regulatory authorities should carefully monitor the rate of Ebitda margins in order to maximize investment. Indeed, Investment is the key driver of price decreases in mobile industry and the reason why it is welfare enhancing. In the wireless industry, the price of megabyte depends more on dynamic effects of investment than on static effects of competition and operating costs. Dynamic effects outweigh static effects after only a few months. Thereby, the positive impact of investment far dominates the harmful impact of margin on welfare.

However, it should be noted that the domination of dynamic effects on static effects is specific to very innovative industries. In sectors with a lower technical progress, impact of investment is lower, and the inverted-U relationship between competition and investment may not occur or may take on a different shape. It is then possible for investment to never outweigh the negative impact of increased margin.

8 Annexes

8.1 Proof of equation (2):

Let us denote $j = i - \delta$, from equation (1), using the approximation of investment $I_t = I_{t_0}(1+\lambda)^{t-t_0}$, the traffic writes:

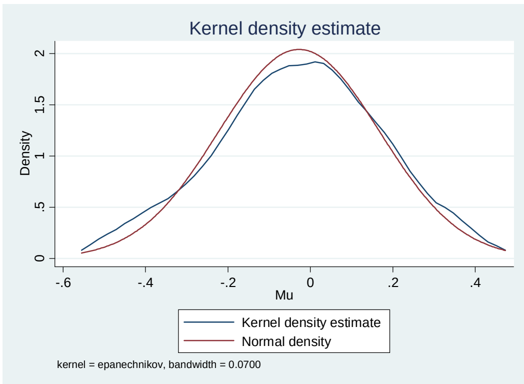
$T_t = A_0 \alpha I_{t_0}(1+\lambda)^{-t_0}\left[\sum_{i=0}^{t}(1+\theta)^i(1+\lambda)^i - \sum_{j=0}^{t-\delta}(1+\theta)^j(1+\lambda)^j\right]$

We know that $\left(1+\theta'\right) = (1+\theta)(1+\lambda)$,thus $\theta' = \theta + \lambda + \theta\lambda$. Notice that $I_0 = I_{t_0}(1+\lambda)^{-t_0}$, the expression becomes: $T_t = A_0 I_0 \alpha \left[\sum_{i=0}^{t}\left(1+\theta'\right)^i - \sum_{j=0}^{t-\delta}\left(1+\theta'\right)^j\right]$.

According to the sum of the terms of a geometric sequence: $T_t = A_0 I_0 \alpha \left(1+\theta'\right)^t \left(\frac{\left(1+\theta'\right)-\left(1+\theta'\right)^{1-\delta}}{\theta'}\right)$.

At time t_0, the initial traffic is $T_{t_0} = A_0 I_0 \alpha \left(1+\theta'\right)^{t_0}\left(\frac{\left(1+\theta'\right)-\left(1+\theta'\right)^{1-\delta}}{\theta'}\right)$. As a result, traffic at time t writes:$T_t = T_{t_0}\left(1+\theta'\right)^{t-t_0}$ .This is equation 2.

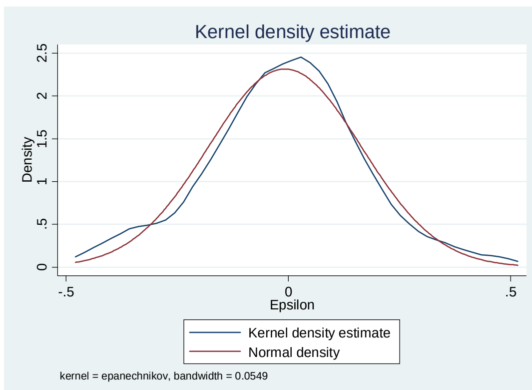
8.2 Distributions $\frac{\mu_t}{I_t}$ and ε_t:



Distribution of $\frac{\mu_t}{I_t}$

S Wilk test	obs	W	V	z	prob>z
μ	100	0.99104	0.740	-0.669	0.74838
ε	120	0.98954	1.006	0.014	0.49451

KS test	obs	pr(skewness)	pr(kurtosis)	adj χ2	prob>χ2
μ	100	0.5545	0.5191	0.78	0.6774
ε	120	0.8778	0.3863	0.79	0.6749



Distribution of ε_t

Shapiro-Wilk test. Null hypothesis: The distribution is normal.
Probability of null hypothesis > 0.1, it can not be rejected.
Kolmogorov-Smirnov test. Null hypothesis: The distribution is normal.
Probability of null hypothesis > 0.1, it can not be rejected.

8.3 Proof of equation (6):

From equation (4): $up_t = \frac{C_t(1+\theta')^{-(t-t_0)}}{T_{t_0}(1-L)_t}$

$\ln(up_t) = \ln(C_t) - \ln(1-L)_t - \ln(T_{t_0}) - (t-t_0)\ln(1+\theta')$

For $t_f = 2012$ and $t_0 = 2006$

$\ln(up_{t_f}) = \ln(C_{t_f}) - \ln(1-L)_{t_f} - \ln(T_{t_f}) - 6\ln(1+\theta')$

Same manner: $\ln(up_{t_0}) = \ln(C_{t_0}) - \ln(1-L)_{t_0} - \ln(T_{t_0})$

Thus $\ln(up_{t_f}) - \ln(up_{t_0}) = \ln(C_{t_f}) - \ln(1-L)_{t_f} - 6\ln(1+\theta') - \ln(C_{t_0}) + \ln(1-L)_{t_0}$

We know that $(1+\theta') = (1+\theta)(1+\lambda)$, therefore $\ln\left(\frac{up_{t_f}}{up_{t_0}}\right) = \ln\left(\frac{C_{t_f}}{C_{t_0}}\right) - \ln\left(\frac{(1-L)_{t_f}}{(1-L)t_0}\right) - 6\ln(1+\theta) - 6\ln(1+\lambda)$

This is equation (6)

8.4 Figure.4, y-axis:

Dynamic effect has two parts, on the one hand, the impact of regular investment according to the rate of technical progress, θ, in the other hand, the impact of the growth in investment, λ. Dynamic effect is written $\ln\left(\frac{De_{t_f}}{De_{t_0}}\right) = -(t_f - t_0)\left[\ln(1+\theta) + \ln(1+\lambda)\right]$. Denoting the impact of regular investment $De\theta$,and the impact of the growth in investment $De\lambda$, such that $\ln\left(\frac{De\theta_{t_f}}{De\theta_{t_0}}\right) = -(t_f - t_0)\ln(1+\theta)$ and $\ln\left(\frac{De\lambda_{t_f}}{De\lambda_{t_0}}\right) = -(t_f - t_0)\ln(1+\lambda)$, it can be written: $\ln\left(\frac{De_{t_f}}{De_{t_0}}\right) = \ln\left(\frac{De\theta_{t_f}}{De\theta_{t_0}}\right) + \ln\left(\frac{De\lambda_{t_f}}{De\lambda_{t_0}}\right)$. The contribution of the growth of investment to the change in unit price in CAGR is $CAGR_{De\lambda(t_f-t_0)} = e^{\frac{1}{(t_f-t_0)}\ln\left(\frac{De\lambda_{t_f}}{De\lambda_{t_0}}\right)} - 1 = \frac{1}{1+\lambda} - 1 = \frac{-\lambda}{1+\lambda}$.

8.5 Erlang's internet formula:

Erlang's internet formula: $P_c(A,N) = \frac{\frac{A^N}{N!}\frac{N}{N-A}}{1+A+...+\frac{A^{N-1}}{(N-1)!}+\frac{A^N}{N!}\frac{N}{N-A}}$ with $A = \frac{D}{c}$ and $N = \frac{C}{c}$

where D is the overall traffic demand, C is the capacity and c is the peak rate allowed by the network. P_c is the probability of congestion.

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