# THE ECONOMIC IMPACT OF TELECOMMUNICATIONS IN SENEGAL (2003-2016): DIMINISHING RETURNS OR RETURN TO SCALE?

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## 1. INTRODUCTION

Studies on the economic impact of telecommunications have been produced for the past two decades confirming, to a large extent, that wireline and wireless telephony, as well as fixed and mobile broadband have an impact on economic growth and, in some cases, on employment and productivity (Hardy, 1980; Karner and Onyeji, 2007; Jensen, 2007; Katz et al., 2010; Katz, 2011; Katz et al., 2012a; Katz et al, 2012b). A critical issue of the evolving research on network externalities of telecommunications is the pattern of impact telecommunications penetration levels may have on output and employment: for example, is there a linear relationship between broadband adoption and economic growth, whereby higher penetration yields larger impact? Or, are we in the presence of more complex causal effects, such as "increasing returns to scale" and/or diminishing returns due to saturation?

For example, the "critical mass" studies (Roller and Waverman, 2001; Shiu and Lam, 2008; Koutroumpis, 2009) indicate that the impact of telecommunications on economic growth may only become significant once the adoption of the technology achieves high penetration levels. On the other hand, some authors (Atkinson et al., 2009; Czernich et al. (2009); Gillett et al. (2006) raise the issue of declining effects due to technology saturation. In other words, while some researchers have raised the question of "return to scale" or need to reach "critical mass" to maximize impact, others have emphasized the "diminishing returns" as key effects to be considered in the assessment of the economic impact of telecommunications.

This study attempts to combine these two effects and raise three hypotheses. First, the economic impact of a single telecommunications technology depends on its stage of diffusion. In other words, the economic contribution of a telecommunications technology is driven by a "return to scale", whereby increasing adoption is imperative in order to maximize impact. Yet, at some point, following an "inverted U" pattern, the impact of telecommunications tends to slow down. Second, this "inverted-U" pattern is rendered even more complex when assessing the relative effects of different telecommunications technologies, such as mobile telephony, fixed broadband, and wireless broadband. Considering that each technology is following different diffusion cycles, it is hypothesized that while one (say, mobile telephony) is undergoing "declining returns"; another one (such as wireless broadband) exhibits a "return to scale". In other words, the role in driving economic contribution is transferred from one technology to the next generation. Third, the economic impact of telecommunications is not homogeneous across industry sectors. As one could intuitively expect, some industries tend to benefit more than others from increased telecommunications development.

Most studies assessing these alternative explanations of telecommunications economic contribution tend to rely methodologically on a dataset composed of a cross-section of countries. However, with longer data sets increasingly available, it has become possible to test for these effects within a single country. The following study explores these issues by relying on a single country dataset: Senegal. It compiles results of prior studies completed by the authors (Katz et al., 2012b; Katz et al., 2014; Katz et al., 2016) and compares them with an assessment of data extending through 2016.

Chapter 2 examines prior literature on telecommunications economic impact with regards to incremental and diminishing effects. Chapter 3 presents the results of prior studies done by the authors on Senegal, while the next three chapters compare them with the results of the models extended through 2016. Thus, chapter 4 focuses on wireless telecommunications, chapter 5 isolates the economic effect of wireless broadband, and chapter 6 tackles the contribution of fixed broadband. Chapter 7 puts all this evidence together and provides support for the studies first two hypotheses. Chapter 8 provides evidence of the heterogeneous impact of telecommunications on Senegalese industries. Finally, Chapter 9 draws conclusions and policy implications.

## 2. THEORETICAL FRAMEWORK AND REVIEW OF THE LITERATURE

In addition to measuring the aggregate economic impact at the macro level, research on the economic impact of telecommunications has focused on the specific processes that underlie this effect. More specifically, two particular issues have been raised so far: first, does the economic impact of telecommunications increase with penetration and, second, can one pinpoint a saturation threshold beyond which decreasing returns to penetration exist? A second related question has not been studied so far but is particularly relevant for policy formulation: if telecommunications has been proven to have an impact on the economy, could the relative impact of different technologies vary according to their development stage, whereby a technology is undergoing a diminishing impact while most contribution effects are transferred to newer technologies? Let's explore each issue in light of the research literature and its theoretical implications.

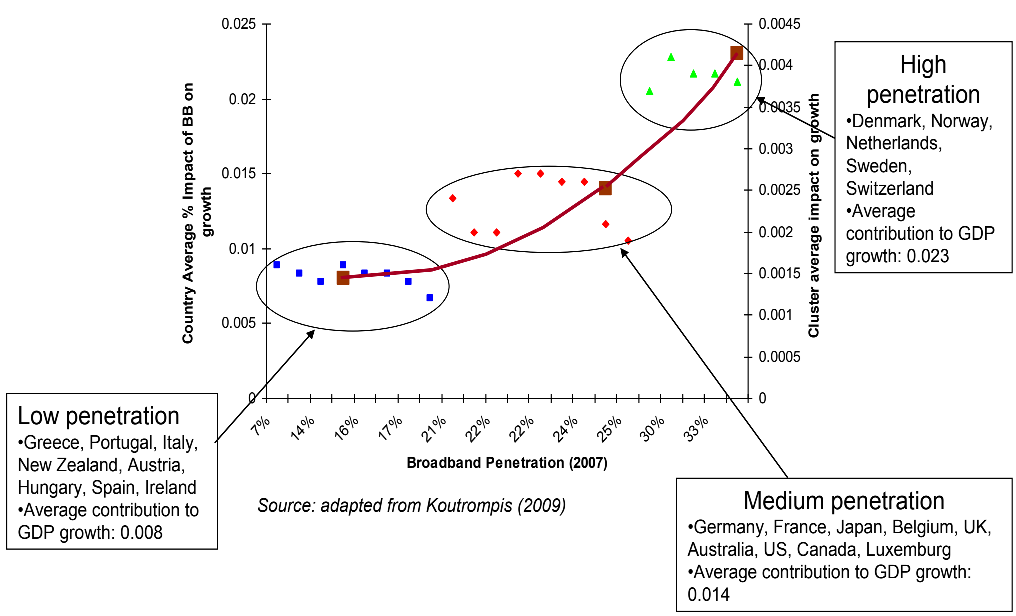
### 2.1. The "return to scale" or "critical mass" effect

According to the research evidence, the impact of telecommunications infrastructure on economic output is maximized once the infrastructure reaches critical mass generally associated with levels of penetration. In the first study identifying this effect, Roeller and Waverman (2001) examined the impact of investment in telecommunications infrastructure on the GDP of 21 OECD countries and 14 developing or newly-industrialized non-OECD countries between 1970 and 1990 and found that the economic contribution of wireline telecommunications was not linear: it was greater in OECD countries than it was in non-OECD countries and in countries that had reached "critical mass". The authors concluded that critical mass needed to influence economic growth is present when telephone penetration reaches 40 main telephone lines per 100 population. The study also found that once the critical mass level is reached, telecommunications investment has a larger impact on economic growth per dollar of investment than other types of infrastructure investment because telecommunications infrastructure exhibits "network effects”.

Following on this study, Shiu et al. (2008) researched the importance of telecommunications development in explaining economic growth in 105 countries. The authors determined that an increase in teledensity is more effective in raising income levels in high-income European countries than in less developed nations, which confirmed the critical mass theory raised by Roller and Waverman. Similarly, Kathuria, et al. (2009) found in their study of wireless economic effects among India’s states that larger growth effects were detected in those states that had achieved a critical mass in mobile infrastructure. By splitting their dataset into high and low penetration states based on the median penetration level of 25% achieved in 2008 they found that the coefficient of impact in their models was higher for high penetration states compared to low penetration states, (0.13 versus 0.10), implying, again, that there is a threshold for critical mass at roughly 25%. Similar evidence was generated by Andrianaivo et al. (2011) in their analysis of mobile telephony in African countries.

The findings in wireline and wireless telephony have been extended to fixed broadband. Koutroumpis (2009) found that for OECD countries the contribution of broadband to economic growth increased with penetration. According to Koutroumpis' research, in countries with low broadband penetration (under 20%), an increase of 1% in broadband adoption contributed to 0.008 % of GDP growth, while in countries with medium penetration (between 20% and 30%), the effect is of 0.014 % and in countries with penetration higher than 30%, the impact of 1% adoption reaches 0.023 (see Graph 1).

**Graph 1. OECD: Percentage of Impact of Broadband on GDP Growth**



Katz et al. (2012) confirmed this finding in their study of Germany's counties (Landkreisse). In this case, they split their dataset between counties with high fixed broadband penetration (average 31%) and low (average 24.8%) and found that the coefficient of economic impact has positive and higher in the counties with high penetration.

The implication of this evidence for developing countries is quite significant. Unless emerging economies do not strive to dramatically increase their penetration of broadband, the economic impact of the technology will be quite limited.

### 2.2. The saturation and "diminishing returns" effect

At the other end of the diffusion process, some authors have pointed out a potential "saturation" effect. They have found that, beyond a certain adoption level, the contribution of a telecommunications technology to the economy tends to diminish. For example, Atkinson at al. (2009) point out that network externalities decline with the build out of networks and the maturation of technology over time. There is evidence that supports this argument. It has been demonstrated in diffusion theory that early technology adopters are generally those who can elicit the higher returns of a given innovation. Conversely, network externalities would tend to diminish over time because those effects would not be as strong for late adopters. Along those lines, Gillett et al. (2006) argued that the relation between broadband penetration and economic impact should not be linear "because broadband will be adopted (…) first by those who get the greatest benefit (while) late adopters (…) will realize a lesser benefit" (p. 10).

To test the saturation hypothesis, Czernich et al. (2009)[1] added dummy variables to account for 10% and 20% broadband penetration to their models explaining broadband contribution to OECD economies. They found that 10% broadband penetration has a significant impact on GDP per capita: between 0.9 and 1.5 percentage points. However, the transition from 10% to 20% yielded non-significant results. This led the authors to postulate that broadband saturation and diminishing returns occurs at the 20% point. Gillett et al. (2006) also included saturation as an independent variable and found that it was negatively related to the increase in economic growth (notwithstanding the possible influence of network effects). In an implicit confirmation of this postulate, Qiang et al. (2009) found that economic impact of a 1% increase in broadband is higher in low and middle-income economies and lower in high-income economies[2]. Similarly, in their study of the impact of broadband in Kentucky, Shideler et al. (2007) found that economic impact is highest around the mean level of broadband saturation at the county level. Again this was due to diminishing returns to scale. According to this last study, a critical amount of broadband infrastructure may be needed to sizably increase employment, but once a community is completely built out, additional broadband

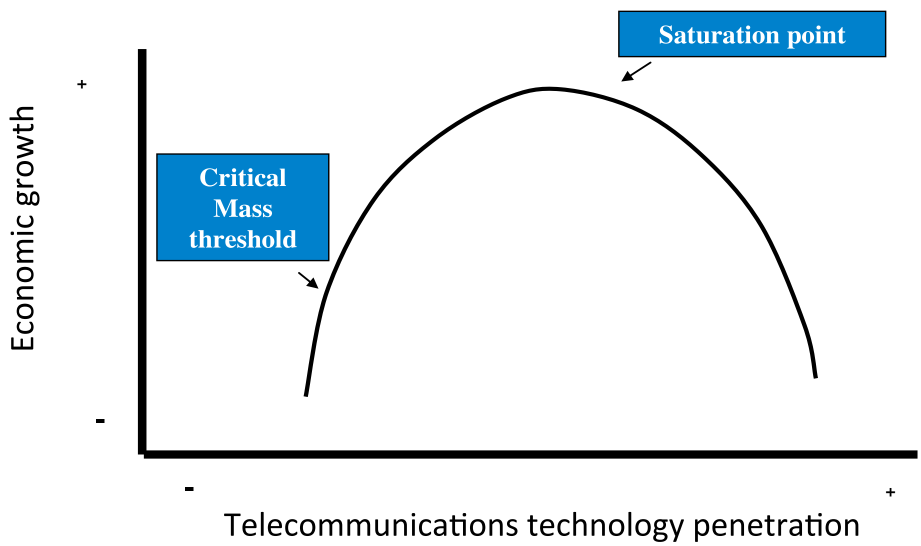
[1] Op. cit. above
[2] Op. cit. above.

infrastructure will not further contribute to employment growth. In the case of mobile telephony, Gruber and Koutroumpis (2011) show as well, that mobile telephony's effects on GDP growth correlate with wireless penetration growth up until penetration rates reach 60%, at which point effects tend to subside.

One should be very careful, however, in interpreting the evidence of "diminishing returns". The saturation evidence still needs to be carefully tested particularly in terms of what is the point beyond which the economic impact tends to diminish. For example, in a study conducted in Germany by this author cited above (Katz et al., 2012b), it was not possible to identify a saturation point for broadband penetration[3]. Furthermore, even if there were to be found confirming evidence of saturation with regard to contribution to GDP or employment creation, that would not put into question the need to achieve universal broadband in terms of the benefits it yields to end users.

With both points of view in mind – need to achieve critical mass and diminishing returns -, it would appear that the strength of the relationship between telecommunications and economic growth is highest once the technology has achieved a certain critical mass but before it reaches saturation (see Figure 1).

**Figure 1. Impact of broadband on output over diffusion process**




*Source: Authors*

Theoretically, it would appear that there is a non-linear (or inverted U shape) relationship between broadband penetration and output. At low levels of broadband penetration, we believe the impact of broadband on the economy is minimal due to the need to reach "critical mass". According to this theory, the impact of telecommunications infrastructure on the economic output is maximized once the

[3] See Katz et al. (2010a).

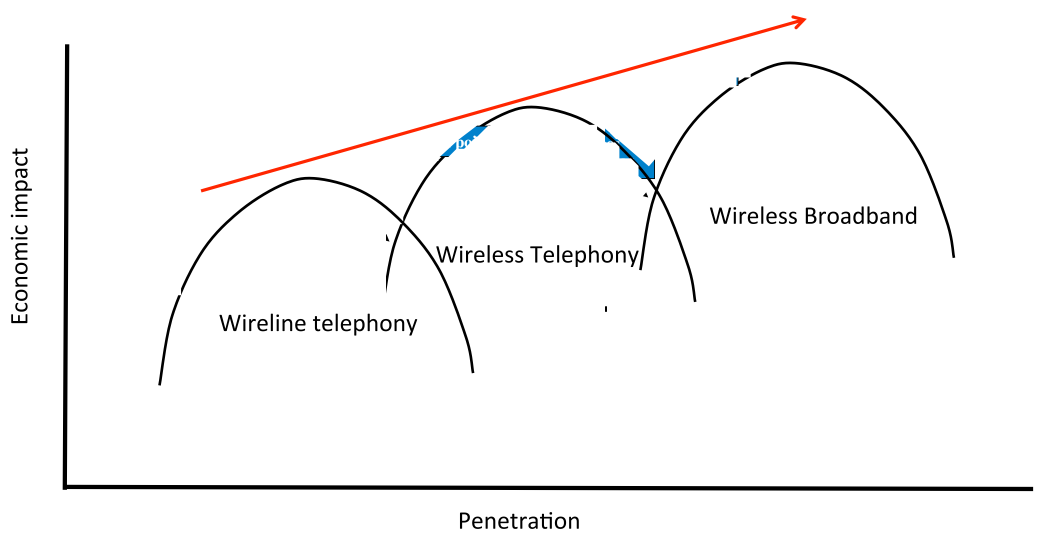
infrastructure reaches a critical mass point generally associated with levels of penetration of industrialized countries. Beyond that point, economic impact tends to slow down, depicting "diminishing returns".

The literature has evidenced an important dispersion in the level of penetration that would indicate a saturation point when economic impact tends to decline: it ranges between 20% and 60%. Moreover, it appears that, according to some studies, a saturation point for broadband penetration is never reached.

## 2.3. The "displacement" effect

A third hypothesis for which there is no clear evidence so far is how both effects – critical mass and saturation – work in terms of successive waves of telecommunications technology. Consider three technologies: voice telecommunications, mobile telecommunications, and mobile broadband. Each of them undergoes a specific process where economic impact is linked to diffusion following the inverted "U" pattern depicted above. According to this, while telecommunications economic impact continues to exist, the sources of impact tend to shift over time. In other words, once the first technology – such as wireline telephony – has completed is diffusion cycle, the lead impact role is transferred to wireless telephony, and after this, wireless broadband (see Figure 2).

**Figure 2. Successive "Inverted-U" cycles**




*Source: Authors*

Obviously, these cycles might not be followed in a "clean" sequential fashion by an emerging country, which might leapfrog the wireline telephony cycle and move on to the wireless one. Likewise, an emerging country might skip altogether the fixed broadband cycle and exhibit successive "inverted-U" cycles only for wireless technologies.

This is a hypothesis that will be tested with Senegal datasets:

- What are the levels of economic impact of mobile telecommunications over time? Can we confirm a critical mass concept and a saturation effect?
- Likewise, can we replicate the same pattern with fixed broadband?
- Finally, if the level of economic impact of mobile telecommunications is declining, do we detect an increase in the contribution of wireless broadband?

## 3. RESULTS OF PRIOR STUDIES FOR SENEGAL

In three successive studies conducted between 2012 and 2014, the authors have run similar structural models to measure the economic impact of telecommunications technologies in Senegal over three periods (see table 1).

**Table 1. Senegal: Econometric analyses of economic impact of telecommunications on GDP growth**

| | Wireless Telecommunications | Fixed Broadband | Wireless Broadband |
|---|---|---|---|
| First period | 2003-2010 | 2004-2010 | 2009-2010 |
| Second period | 2004-2011 | 2004-2011 | 2009-2012 |
| Third period | 2003-2014 | 2004-2014 | 2009-2014 |

*Sources: Katz and Koutroumpis (2012); Katz and Callorda (2014); Katz and Callorda (2016).*

The models used for the three studies were similar. For example, to measure the economic impact of wireless telecommunications on the GDP, a structural model consisting of four equations was constructed: an aggregate production function modeling the economy and, subsequently, three functions: demand, supply and output. The last three functions model the mobile market operation and, controlling for the reverse effects, the actual impact of the infrastructures is estimated. In the production function, GDP is linked to the fixed stock of capital, labor and the mobile infrastructure proxied by mobile penetration (while in the first three studies, total subscriptions penetration was used, in the one under consideration we shifted to unique subscriber penetration to control for the "double SIM card effect"). The demand function links mobile penetration to the average consumption propensity of individuals proxied by GDP per capita, the price of a mobile service proxied by ARPU (Average Revenue per User), the percent rural population, and the level of competitive intensity in the mobile market measured by the HHI (Herfindahl Hirschman) index. The supply function links aggregate mobile revenues to mobile price levels proxied by ARPU, the industry concentration index of the mobile market (HHI), and GDP per capita. The infrastructure equation links annual change in mobile penetration to mobile revenues, used as a proxy of the capital invested in a country during one year.

The econometric specification of the model is as follows:

Aggregate Production function:

$$GDPit=a_1K_{it}+a_2L_{it}+a_3Mob\_Pen_{it}+ e_{it} \quad (1)$$

Demand function:

$$Mob\_Pen_{it}=b_1Rural_{it}+b_2Mob\_Price_{it}+b_3GDPC_{it}+b_4HHI_{it}+e_{it} \quad (2)$$

Supply function:

$$Mob\_Rev_{it}=c_1MobPr_{it}+c_2GDPC_{it}+c_3HHI_{it}+\varepsilon_{3it} \quad (3)$$

Output function:

$$\Delta Mob\_Pen_{it} = d_1 Mob\_Rev_{it} + \varepsilon_{4it} \quad (4)$$

Similar models were used to measure the impact on GDP of fixed broadband and wireless broadband. The results for the first three periods presented in prior papers can be synthesized as follows:

- Wireless telecommunications: the economic impact of wireless telecommunications increases with penetration, confirming the "critical mass" theory;
- Fixed broadband: fixed broadband did not have statistically significant effects in either the first or the second period due to low penetration and limited quality of service (5.30% household and 0.63% individual penetration in the first period, and 6.08% household and 0.73% individual penetration in the second). However, in the third period when penetration increased (6.23% household and 0.63% individual penetration), the model indicated that each 1% increase in fixed broadband penetration yields 0.050% of GDP growth. Again, these results would appear to initially confirm the "critical mass" theory of telecommunications economic impact;
- Wireless broadband: at penetration levels of 0.29% (first period), wireless broadband did not have indirect economic effects; however, at 3.42% penetration (second period), wireless broadband appeared to show some economic effect. Also, at 8.14% penetration (third period), each 1% increase in mobile broadband penetration yields 0.040% of GDP growth.

Table 2 presents all coefficients of impact for all technologies for the three periods studied in prior studies.

**Table 2. Impact on GDP growth every 1% increase in technology penetration**

| | Wireless telecommunications | Fixed broadband | Wireless Broadband |
|---|---|---|---|
| First period | 0.044% | No impact | No impact |
| Second period | 0.061% | No impact | 0.022% |
| Third period | 0.091% | 0.050% | 0.040% |

*Source: Telecom Advisory Services analysis*

As data in Table 2 indicates, the results of the first three study waves appear to confirm the "return to scale" effect, which stipulates that an increase in telecommunications technology penetration yields higher economic contribution. At the same time, results would indicate that below an adoption threshold, telecommunications do not have a verifiable aggregate economic contribution. The results of the second and third wave provided support for a hypothesis that would indicate that higher penetration levels in the fourth period (2009-2016) would yield more important economic effects. On the other hand, the question remained as to whether there appeared to be an inflexion or saturation point for any technology or, whether the lead role in economic contribution would have been transferred from one technology to the next generation. This is the focus of the next three chapters, which present the results of the fourth and last period.

## 4. WIRELESS TELECOMMUNICATIONS EFFECT IN THE FOURTH PERIOD STUDIED (2009-2016)

A similar structural model to test the wireless telecommunications economic contribution for the fourth period was run. However, as mentioned before, in order to control for "double-SIM card" effect, the mobile penetration variable was changed from "total penetration" to "unique subscriber penetration". As it will show later, that required re-running the third period model for normalization purposes. On the other hand, the first two periods were not re-run since the double SIM card effect was not prevalent at early stages of adoption.

In this case of the fourth period, the model was run for wireless telecommunications (which does not distinguish between voice and data) with an extended time series (96 observations), indicating that every increase of 1% in wireless telecommunications yields 0.086% growth in GDP. The equation results were statistically significant (see Table 3).

**Table 3. Senegal: Economic impact of mobile telecommunications (2009-2016)**

Three-stage least-squares regression

| Equation | Obs | Parms | RMSE | "R-sq" | chi2 | P |
|---|---|---|---|---|---|---|
| lgdp2 | 96 | 14 | .0041708 | 0.9979 | 2.54e+09 | 0.0000 |
| lmobusers | 96 | 5 | .017944 | 0.9862 | 9075.70 | 0.0000 |
| lrevenuemo~e | 96 | 3 | .0280871 | 0.7604 | 308.14 | 0.0000 |
| mobgrowth | 96 | 1 | .0035609 | 0.4167 | 108.46 | 0.0000 |

| | Coef. | Std. Err. | z | P>\|z\| | [95% Conf. | Interval] |
|---|---|---|---|---|---|---|
| lgdp2 | | | | | | |
| lfcapital_2 | .1540196 | .0281479 | 5.47 | 0.000 | .0988507 | .2091885 |
| llabedu_1 | -.1528885 | .0198391 | -7.71 | 0.000 | -.1917724 | -.1140046 |
| lmobusers | .0860968 | .0506132 | 1.70 | 0.089 | -.0131033 | .1852969 |
| yr_10 | 19.92331 | .2787927 | 71.46 | 0.000 | 19.37689 | 20.46974 |
| yr_11 | 19.95381 | .2821161 | 70.73 | 0.000 | 19.40087 | 20.50674 |
| yr_12 | 19.98239 | .2878056 | 69.43 | 0.000 | 19.4183 | 20.54648 |
| yr_13 | 20.01436 | .2922264 | 68.49 | 0.000 | 19.44161 | 20.58712 |
| yr_14 | 20.03923 | .2968313 | 67.51 | 0.000 | 19.45745 | 20.62101 |
| yr_15 | 20.06874 | .2995161 | 67.00 | 0.000 | 19.4817 | 20.65578 |
| yr_16 | 20.11339 | .3018174 | 66.64 | 0.000 | 19.52184 | 20.70494 |
| yr_17 | 20.16558 | .3041795 | 66.30 | 0.000 | 19.5694 | 20.76176 |
| qt_1 | -.0275073 | .0027639 | -9.95 | 0.000 | -.0329244 | -.0220902 |
| qt_2 | -.0186844 | .0018936 | -9.87 | 0.000 | -.0223958 | -.014973 |
| qt_3 | -.0088969 | .0013893 | -6.40 | 0.000 | -.0116199 | -.0061738 |
| _cons | (omitted) | | | | | |
| lmobusers | | | | | | |
| lnrural | -7.611879 | 1.434147 | -5.31 | 0.000 | -10.42275 | -4.801003 |
| lnfixed | .1403347 | .0348441 | 4.03 | 0.000 | .0720415 | .2086279 |
| lgdpc2 | -1.079052 | .2014562 | -5.36 | 0.000 | -1.473899 | -.684205 |
| lmobcost | -.4474527 | .0613979 | -7.29 | 0.000 | -.5677904 | -.3271151 |
| hhi_mobile | -.1295586 | .0548003 | -2.36 | 0.018 | -.2369652 | -.022152 |
| _cons | 41.1674 | 6.055162 | 6.80 | 0.000 | 29.2995 | 53.0353 |
| lrevenuemo~e | | | | | | |
| lgdpc2 | .7402485 | .1545699 | 4.79 | 0.000 | .4372969 | 1.0432 |
| lmobcost | -.0021006 | .0419733 | -0.05 | 0.960 | -.0843668 | .0801655 |
| hhi_mobile | -.3599271 | .0825163 | -4.36 | 0.000 | -.5216562 | -.1981981 |
| _cons | 18.56407 | 1.064235 | 17.44 | 0.000 | 16.47821 | 20.64994 |
| mobgrowth | | | | | | |
| lrevenuemo~e | -.0646025 | .0062031 | -10.41 | 0.000 | -.0767604 | -.0524447 |
| _cons | 1.220694 | .1166899 | 10.46 | 0.000 | .9919863 | 1.449402 |

Endogenous variables: lgdp2 lmobusers lrevenuemobile mobgrowth
Exogenous variables: lfcapital_2 llabedu_1 yr_10 yr_11 yr_12 yr_13 yr_14 yr_15 yr_16 yr_17 qt_1 qt_2 qt_3 lnrural lnfixed lgdpc2 lmobcost hhi_mobile

*Source: Telecom Advisory Services analysis*

As mentioned above, the model was also run for the fourth period changing the mobile penetration variable from "total subcriber penetration" to "unique subscribers". Additionally, the model was run for the 2007-2014 period to standardize results around a seven year interval. The results for this new 2007-2014 period indicate that every increase of 1% in wireless telecommunications yields 0.166% growth in GDP. Again, the results were statistically significant (see Table 4).

**Table 4. Senegal: Economic impact of mobile telecommunications (2007-2014)**

Three-stage least-squares regression

| Equation | Obs | Parms | RMSE | "R-sq" | chi2 | P |
|---|---|---|---|---|---|---|
| lgdp2 | 96 | 13 | .0028147 | 0.9987 | 75349.30 | 0.0000 |
| lmobusers | 96 | 5 | .0735983 | 0.9231 | 1329.68 | 0.0000 |
| lrevenuemo~e | 96 | 3 | .0750131 | 0.7952 | 375.25 | 0.0000 |
| mobgrowth | 96 | 1 | .0082803 | 0.1677 | 16.78 | 0.0000 |

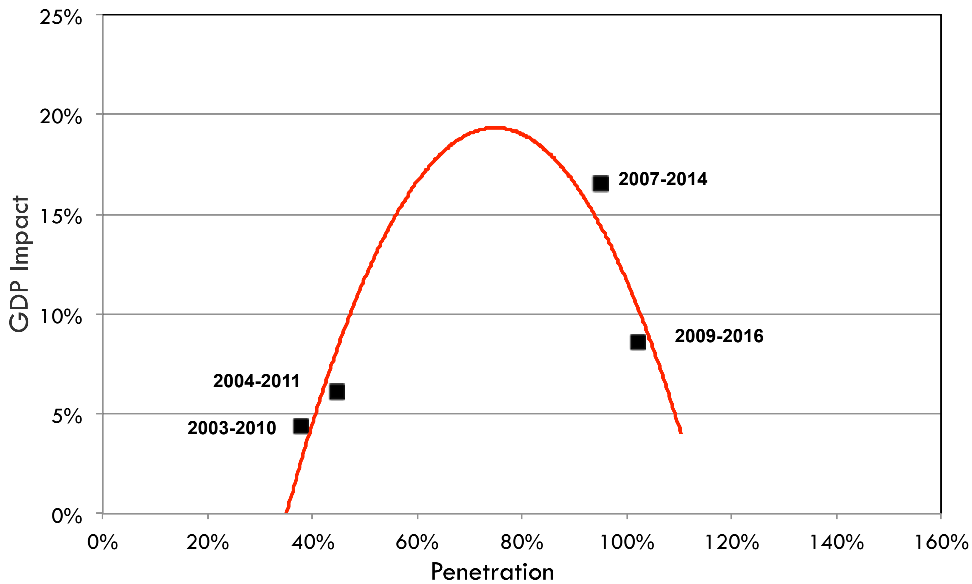
| | Coef. | Std. Err. | z | P>\|z\| | [95% Conf. | Interval] |
|---|---|---|---|---|---|---|
| lgdp2 | | | | | | |
| lfcapital_2 | .1158718 | .0167443 | 6.92 | 0.000 | .0830536 | .14869 |
| llabedu_1 | -.1141071 | .0130499 | -8.74 | 0.000 | -.1396844 | -.0885298 |
| lmobusers | .1655283 | .017417 | 9.50 | 0.000 | .1313917 | .199665 |
| yr_8 | -.1434697 | .0122407 | -11.72 | 0.000 | -.1674611 | -.1194782 |
| yr_9 | -.1292097 | .0086104 | -15.01 | 0.000 | -.1460859 | -.1123336 |
| yr_10 | -.1091457 | .0068427 | -15.95 | 0.000 | -.1225572 | -.0957342 |
| yr_11 | -.0891086 | .0058939 | -15.12 | 0.000 | -.1006605 | -.0775567 |
| yr_12 | -.0725178 | .0041908 | -17.30 | 0.000 | -.0807315 | -.0643041 |
| yr_13 | -.0480383 | .0030783 | -15.61 | 0.000 | -.0540718 | -.0420049 |
| yr_14 | -.0272667 | .0016377 | -16.65 | 0.000 | -.0304765 | -.0240569 |
| qt_1 | -.0176884 | .0013691 | -12.92 | 0.000 | -.0203718 | -.015005 |
| qt_2 | -.0129387 | .0010058 | -12.86 | 0.000 | -.0149101 | -.0109674 |
| qt_3 | -.0059622 | .0008535 | -6.99 | 0.000 | -.0076351 | -.0042892 |
| _cons | 19.88518 | .1180844 | 168.40 | 0.000 | 19.65374 | 20.11662 |
| lmobusers | | | | | | |
| lnrural | -10.05459 | 2.817031 | -3.57 | 0.000 | -15.57587 | -4.533308 |
| lnfixed | .4797023 | .094484 | 5.08 | 0.000 | .294517 | .6648876 |
| lgdpc2 | 12.26847 | 2.147398 | 5.71 | 0.000 | 8.05965 | 16.4773 |
| lmobcost | .0375329 | .1127419 | 0.33 | 0.739 | -.1834372 | .258503 |
| hhi_mobile | -.0780965 | .2846166 | -0.27 | 0.784 | -.6359347 | .4797418 |
| _cons | -10.7599 | 16.47745 | -0.65 | 0.514 | -43.05511 | 21.5353 |
| lrevenuemo~e | | | | | | |
| lgdpc2 | 10.3486 | 2.044041 | 5.06 | 0.000 | 6.342353 | 14.35485 |
| lmobcost | .3858918 | .0866488 | 4.45 | 0.000 | .2160633 | .5557204 |
| hhi_mobile | -.8098561 | .2727186 | -2.97 | 0.003 | -1.344375 | -.2753375 |
| _cons | -21.18734 | 10.98328 | -1.93 | 0.054 | -42.71418 | .3395016 |
| mobgrowth | | | | | | |
| lrevenuemo~e | -.0207984 | .0050769 | -4.10 | 0.000 | -.030749 | -.0108479 |
| _cons | .3989881 | .0950426 | 4.20 | 0.000 | .2127081 | .5852682 |

Endogenous variables: lgdp2 lmobusers lrevenuemobile mobgrowth
Exogenous variables: lfcapital_2 llabedu_1 yr_8 yr_9 yr_10 yr_11 yr_12 yr_13 yr_14 qt_1 qt_2 qt_3 lnrural lnfixed lgdpc2 lmobcost hhi_mobile

*Source: Telecom Advisory Services analysis*

These new values for wireless telecommunications allow comparing results with prior iterations of the model, confirming that for mobile telecommunications (which included voice and data), a saturation point and diminishing returns might have appeared (see Graph 2).

**Graph 2. Senegal: Mobile Telecommunications Economic Impact vs. Wireless penetration**




*Source: Telecom Advisory Services analysis*

In sum, between 2014 and 2016, while wireless telecommunications penetration increased marginally, its contribution to GDP appears to be declining. According to these results, this would indicate that the economic contribution of mobile telecommunications has reached a saturation point and that the primary driver of economic contribution could be transferred to wireless broadband. To test for this effect, we need to isolate the economic impact of wireless broadband.

## 5. MOBILE BROADBAND EFFECT IN THE FOURTH PERIOD STUDIED (2010-2016)

The same econometric structural model specified for the prior three periods (2009-2010, 2009-2011, 2009-2014) was run for the 2010-2016 mobile broadband dataset, although the wireless broadband penetration variable was changed from "total subscriptions" to "unique subscribers". The econometric model run confirms again the increasing returns to scale. In this case, each 1% increase in mobile broadband penetration yields 0.104% of GDP growth. Again, the results were statistically significant (see table 5).

**Table 5. Senegal: Economic impact of mobile broadband (2010-2016)**

Three-stage least-squares regression

| Equation | Obs | Parms | RMSE | "R-sq" | chi2 | P |
|---|---|---|---|---|---|---|
| lgdp2 | 82 | 13 | .0041929 | 0.9974 | 2.19e+09 | 0.0000 |
| lmbbusers | 82 | 4 | .0145245 | 0.9969 | 26974.90 | 0.0000 |
| lrevenuembb | 82 | 3 | .3641097 | 0.9452 | 1426.09 | 0.0000 |
| mbbgrowth | 82 | 1 | .0384943 | 0.6240 | 145.43 | 0.0000 |

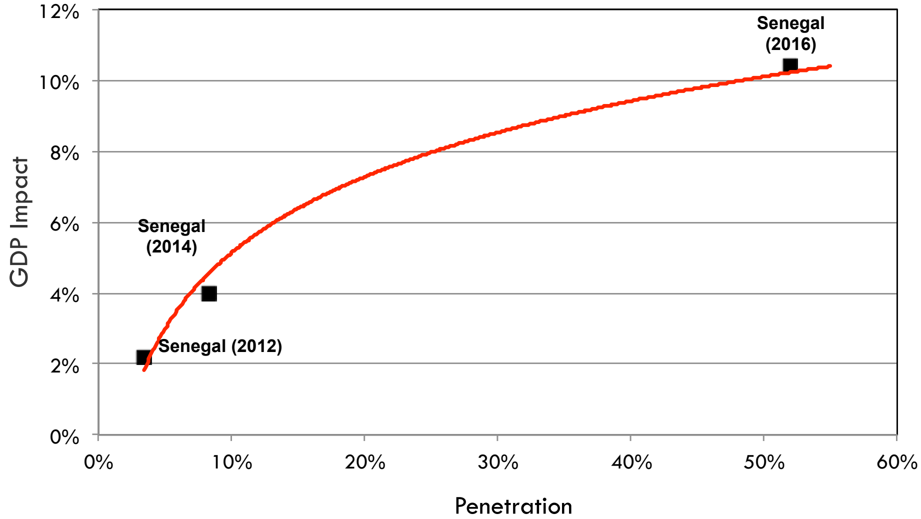
| | Coef. | Std. Err. | z | P>\|z\| | [95% Conf. | Interval] |
|---|---|---|---|---|---|---|
| lgdp2 | | | | | | |
| lfcapital_2 | .3295213 | .0473752 | 6.96 | 0.000 | .2366675 | .4223751 |
| llabedu_1 | -.2216953 | .0213338 | -10.39 | 0.000 | -.2635088 | -.1798817 |
| lmbbusers | .1040508 | .0282972 | 3.68 | 0.000 | .0485893 | .1595122 |
| yr_11 | 19.20557 | .2598867 | 73.90 | 0.000 | 18.69621 | 19.71494 |
| yr_12 | 19.22006 | .2643106 | 72.72 | 0.000 | 18.70202 | 19.7381 |
| yr_13 | 19.24181 | .2679383 | 71.81 | 0.000 | 18.71666 | 19.76696 |
| yr_14 | 19.24886 | .2729801 | 70.51 | 0.000 | 18.71382 | 19.78389 |
| yr_15 | 19.2585 | .2775851 | 69.38 | 0.000 | 18.71444 | 19.80255 |
| yr_16 | 19.28586 | .2813976 | 68.54 | 0.000 | 18.73433 | 19.83739 |
| yr_17 | 19.32048 | .2856561 | 67.64 | 0.000 | 18.76061 | 19.88036 |
| qt_1 | -.0157901 | .0037814 | -4.18 | 0.000 | -.0232016 | -.0083786 |
| qt_2 | -.0107362 | .0026156 | -4.10 | 0.000 | -.0158627 | -.0056097 |
| qt_3 | -.0059788 | .0016271 | -3.67 | 0.000 | -.0091679 | -.0027897 |
| _cons | (omitted) | | | | | |
| lmbbusers | | | | | | |
| lnrural | -31.07636 | .8085029 | -38.44 | 0.000 | -32.661 | -29.49173 |
| lgdpc2 | -2.28573 | .1840773 | -12.42 | 0.000 | -2.646515 | -1.924945 |
| lmbbcost | .0700107 | .0050613 | 13.83 | 0.000 | .0600907 | .0799308 |
| hhi_mb | -.1423898 | .0176717 | -8.06 | 0.000 | -.1770257 | -.1077539 |
| _cons | 139.4482 | 3.731306 | 37.37 | 0.000 | 132.1349 | 146.7614 |
| lrevenuembb | | | | | | |
| lgdpc2 | 11.01926 | 3.462414 | 3.18 | 0.001 | 4.233048 | 17.80546 |
| lmbbcost | .3200898 | .1208899 | 2.65 | 0.008 | .08315 | .5570296 |
| hhi_mb | -5.393197 | .2131303 | -25.30 | 0.000 | -5.810925 | -4.975469 |
| _cons | 12.91157 | 15.95255 | 0.81 | 0.418 | -18.35486 | 44.178 |
| mbbgrowth | | | | | | |
| lrevenuembb | -.0329661 | .0027337 | -12.06 | 0.000 | -.038324 | -.0276083 |
| _cons | .6120626 | .0447353 | 13.68 | 0.000 | .524383 | .6997422 |

Endogenous variables: lgdp2 lmbbusers lrevenuembb mbbgrowth
Exogenous variables: lfcapital_2 llabedu_1 yr_11 yr_12 yr_13 yr_14 yr_15 yr_16 yr_17 qt_1 qt_2 qt_3 lnrural lgdpc2 lmbbcost hhi_mb

*Source: Telecom Advisory Services analysis*

The increase in mobile broadband penetration yields higher impact on GDP. Therefore, the results confirm the hypothesis of increasing returns to a growth in mobile broadband penetration (see Graph 3).

**Graph 3. Senegal: Mobile Broadband penetration vs. Mobile Broadband Economic Impact**




*Source: Telecom Advisory Services analysis*

The significant increase in economic impact of mobile broadband between 2014 and 2016 is the result not only of an increase in penetration but also because this technology is assuming the preeminent role in providing Internet connectivity. Fixed broadband in the country remains fairly undeveloped both in terms of the number of subscribers, pricing and coverage, as will be shown in the next chapter.

## 6. FIXED BROADBAND EFFECT IN THE FOURTH PERIOD STUDIED (2004-2016)

Lastly, we specified the structural model for fixed broadband for the period 2004-2016. The econometric model run confirms again the increasing returns to scale. In this case, each 1% increase in fixed broadband penetration yields 0.068% of GDP growth, while in the 2004-2014 study, the corresponding coefficient was 0.050. As in the other models, the results were statistically significant (see table 6).

**Table 6. Senegal: Economic impact of fixed broadband (2004-2016)**

Three-stage least-squares regression

| Equation | Obs | Parms | RMSE | "R-sq" | chi2 | P |
|---|---|---|---|---|---|---|
| lgdp1 | 156 | 18 | .0115629 | 0.9974 | 67247.89 | 0.0000 |
| lfbbusers | 156 | 5 | .1665989 | 0.9614 | 4697.55 | 0.0000 |
| lrevenuefbb | 156 | 3 | .2601785 | 0.9138 | 1675.74 | 0.0000 |
| fbbgrowth | 156 | 1 | .0113848 | 0.8604 | 956.97 | 0.0000 |

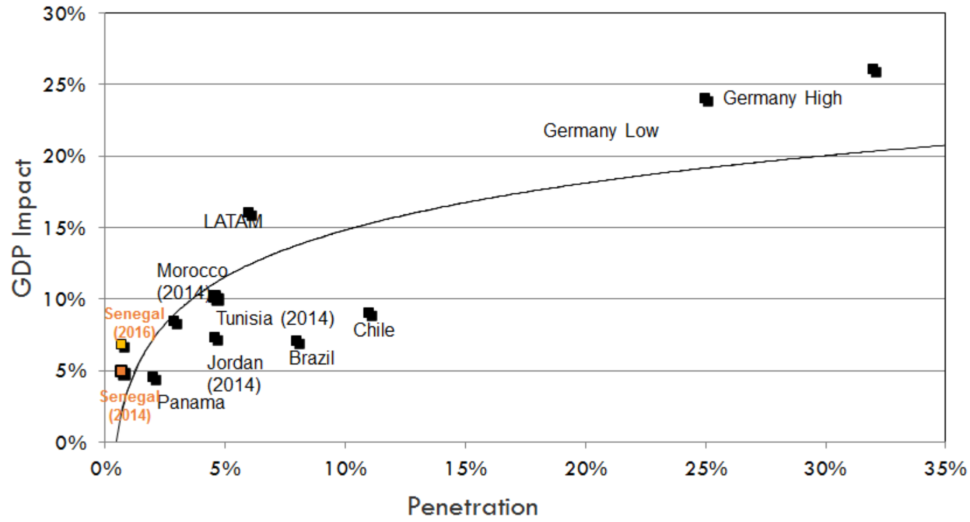
| | Coef. | Std. Err. | z | P>\|z\| | [95% Conf. | Interval] |
|---|---|---|---|---|---|---|
| lgdp1 | | | | | | |
| lfcapital_3 | .4442447 | .0361992 | 12.27 | 0.000 | .3732956 | .5151938 |
| llabedu_1 | .1292822 | .0441487 | 2.93 | 0.003 | .0427524 | .215812 |
| lfbbusers | .0684343 | .0131414 | 5.21 | 0.000 | .0426775 | .094191 |
| yr_6 | -.0201432 | .0115679 | -1.74 | 0.082 | -.0428159 | .0025295 |
| yr_7 | -.0594818 | .0176326 | -3.37 | 0.001 | -.094041 | -.0249226 |
| yr_8 | -.0404151 | .0207304 | -1.95 | 0.051 | -.081046 | .0002158 |
| yr_9 | .0119078 | .0246475 | 0.48 | 0.629 | -.0364004 | .0602161 |
| yr_10 | .0480185 | .0289674 | 1.66 | 0.097 | -.0087565 | .1047936 |
| yr_11 | .0687546 | .0322223 | 2.13 | 0.033 | .0056 | .1319092 |
| yr_12 | .0521969 | .0368878 | 1.42 | 0.157 | -.0201019 | .1244956 |
| yr_13 | .0460976 | .0398546 | 1.16 | 0.247 | -.032016 | .1242111 |
| yr_14 | .0430669 | .0401928 | 1.07 | 0.284 | -.0357095 | .1218433 |
| yr_15 | .0408707 | .040135 | 1.02 | 0.309 | -.0377925 | .1195338 |
| yr_16 | .0151045 | .0406497 | 0.37 | 0.710 | -.0645675 | .0947765 |
| yr_17 | .0098025 | .0405629 | 0.24 | 0.809 | -.0696993 | .0893042 |
| qt_1 | -.0019874 | .0034844 | -0.57 | 0.568 | -.0088166 | .0048418 |
| qt_2 | -.0016924 | .0028874 | -0.59 | 0.558 | -.0073516 | .0039669 |
| qt_3 | -.00101 | .002515 | -0.40 | 0.688 | -.0059393 | .0039193 |
| _cons | 4.716924 | .185411 | 25.44 | 0.000 | 4.353525 | 5.080323 |
| lfbbusers | | | | | | |
| lnrural | -47.28889 | 3.967907 | -11.92 | 0.000 | -55.06584 | -39.51193 |
| lnfixed | 2.642451 | .2089451 | 12.65 | 0.000 | 2.232926 | 3.051976 |
| lgdpc1 | 3.590643 | .1315843 | 27.29 | 0.000 | 3.332742 | 3.848543 |
| lfbbcost | -.4768858 | .1253051 | -3.81 | 0.000 | -.7224792 | -.2312924 |
| hhi_fbb | 1.213645 | .1585693 | 7.65 | 0.000 | .9028546 | 1.524435 |
| _cons | 156.4823 | 14.6491 | 10.68 | 0.000 | 127.7706 | 185.194 |
| lrevenuefbb | | | | | | |
| lgdpc1 | 4.716374 | .1826361 | 25.82 | 0.000 | 4.358414 | 5.074334 |
| lfbbcost | .3792768 | .1701611 | 2.23 | 0.026 | .0457671 | .7127864 |
| hhi_fbb | -.8359419 | .0936193 | -8.93 | 0.000 | -1.019432 | -.6524515 |
| _cons | -4.263566 | 1.404433 | -3.04 | 0.002 | -7.016203 | -1.510929 |
| fbbgrowth | | | | | | |
| lrevenuefbb | -.0318851 | .0010307 | -30.93 | 0.000 | -.0339053 | -.029865 |
| _cons | .5150356 | .015963 | 32.26 | 0.000 | .4837487 | .5463225 |

Endogenous variables: lgdp1 lfbbusers lrevenuefbb fbbgrowth
Exogenous variables: lfcapital_3 llabedu_1 yr_6 yr_7 yr_8 yr_9 yr_10 yr_11 yr_12 yr_13 yr_14 yr_15 yr_16 yr_17 qt_1 qt_2 qt_3 lnrural lnfixed lgdpc1 lfbbcost hhi_fbb

*Source: Telecom Advisory Services analysis*

Interestingly enough, the penetration in 2016 was relatively stable since 2012 (5.82% of households in 2016 vs. 5.30% in 2012). The reason why an economic effect is now detected is due to the fact that the model is now relying on a larger number of observations (due to a longer time series). An additional reason that the coefficient of economic impact has increased despite a stagnant subscriber base is that pricing has declined 55%, leading users to purchase higher speed plans, which in turn accentuated the economic impact. That being said, the Senegal coefficient of economic impact is fairly consistent with a cross-section of countries (see Graph 4).

**Graph 4. Fixed Broadband Economic Impact vs. Fixed Broadband penetration**




*Source: Telecom Advisory Services analysis*

As Graph 4 indicates, now that a fixed broadband effect has been detected in Senegal, the coefficient is in line with the exponential growth curve developed on the basis of other studies.

## 7. DIMINISHING RETURNS, SATURATION AND CRITICAL MASS IN TELECOMMUNICATIONS IN SENEGAL

The results of the models run for the fourth period amply confirm the hypotheses (see table 7).

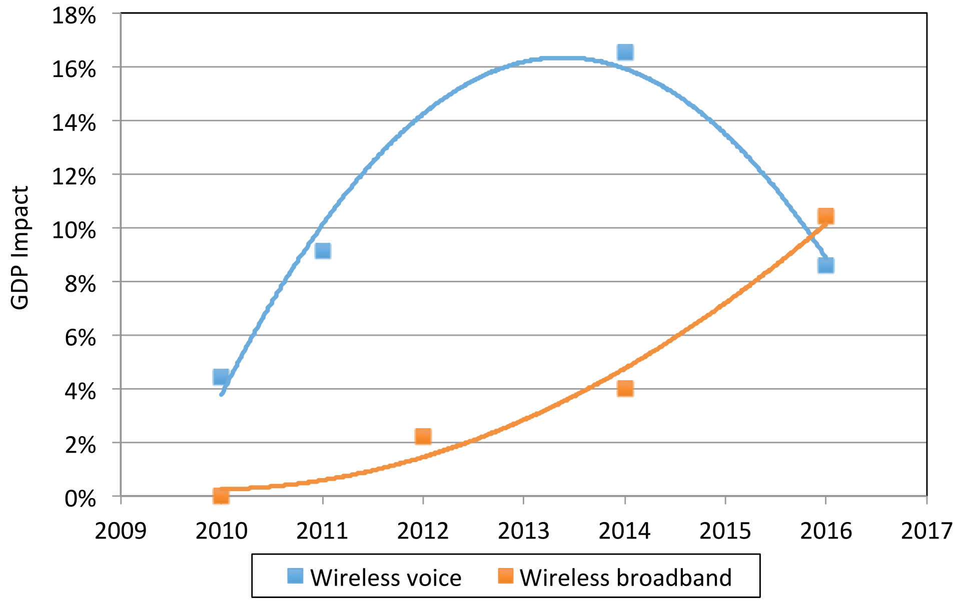
**Table 7. Senegal: Impact on GDP growth every 1% increase in technology penetration**

| | Wireless telecommunications | Fixed broadband | Wireless Broadband |
|---|---|---|---|
| First period | 0.044% | No impact | No impact |
| Second period | 0.061% | No impact | 0.022% |
| Third period | 0.166% | 0.050% | 0.040% |
| Fourth period | 0.086% | 0.068% | 0.104% |

*Source: Telecom Advisory Services analysis*

In sum, the results of the fourth wave confirm the “diminishing returns” effect in wireless telecommunications (voice and data) and “returns to scale” effect in wireless broadband. When plotted over time, the relationship between wireless voice and wireless broadband in terms of their economic impact is clear in Graph 5.

**Graph 5. Senegal: Impact on GDP growth every 1% increase in technology penetration**




*Source: Telecom Advisory Services analysis*

As Graph 5 indicates, when wireless voice starts depicting declining returns on its economic contribution relative to the growth in penetration, wireless broadband takes up the lead in driving the impact of telecommunications on GDP growth.

In the case of fixed broadband, a longer time series has allowed the identification of an economic contribution as well, although it is still difficult to discern what the ultimate effect might be. In fact, it could very well happen that, since Senegal is leapfrogging fixed broadband, the "critical mass" and "diminishing returns" effects will not be able to be tested.

The increase in adoption of these technologies has generated an increasing contribution to GDP growth. Table 8 depicts the average annual impact, in US dollars, of each technology.

**Table 8. Senegal: Annual contribution to GDP growth (in US$)**

| | Wireless Telecommunications | Fixed Broadband | Wireless Broadband |
|---|---|---|---|
| First period[4] | US$ 210 mm (between 2003 and 2010) | No impact | No impact |
| Second period[5] | US$ 176 mm (between 2Q05 and 2Q13) | No impact | US$ 173 mm (between 2Q12 and 2Q13) |
| Third period[6] | US$ 251 mm (between 4Q07 and 4Q14) | US$ 141 mm (between 4Q04 and 4Q14) | US$ 255 mm (between 4Q13 and 4Q14) |
| Fourth period[7] | US$ 110 mm (between 4Q09 and 4Q16) | US$ 185 mm (between 4Q04 and 4Q16) | US$ 154 mm (between 4Q12 and 4Q16) |

*Source: Telecom Advisory Services analysis*

It is important to underline that in the first, second and third periods, the annual impact of wireless broadband was fairly close to that of wireless telecommunications (voice and data). This implies that in those periods (from 2005 to 2014), economic growth was triggered primarily by voice telecommunications. In the fourth period, the annual impact of wireless telecommunications declines to US$ 110 million from US$ 251 million.  On the other hand, the contribution of wireless broadband has increased reflecting that all the economic effect of wireless resides on mobile and that even some of the voice traffic is being conducted via data.

In the following table, the annual contribution to the Senegalese GDP growth is measured in percentage points to ascertain telecommunications economic weight.

**Table 9. Senegal: Contribution to GDP growth (in relationship with 2016 GDP)**

| | Wireless Telecommunications | Fixed Broadband | Wireless Broadband |
|---|---|---|---|
| First period | 1.40% (between 2003 and 2010) | No impact | No impact |
| Second period | 1.17% (between 2Q05 and 2Q13) | No impact | 1.15% (between 2Q12 and 2Q13) |
| Third period | 1.67% (between 4Q07 and 4Q14) | 0.94% (between 4Q04 and 4Q14) | 1.69% (between 4Q13 and 4Q14) |
| Fourth period | 0.77% (between 4Q09 and 4Q16) | 1.26% (between 4Q04 and 4Q16) | 1.03% (between 4Q12 and 4Q16) |

*Source: Telecom Advisory Services analysis*

It is important to note that, while mobile broadband contribution declines in the fourth period, this is because that the penetration cycle of the technology is slowing down (incremental unique subscribers increased 9.5% between 2015 and 2016).

[4] Katz, R. and Koutroumpis, P. (2012b). *The Economic Impact of Telecommunications in Senegal.*
[5] Katz, R. and Callorda, F.. (2014). *Assessment of the Economic Impact of Telecommunications in Senegal*.
[6] Katz, R. and Callorda, F. (2016) *Assessment of the Economic Impact of Telecommunications in Senegal (2003-20144)* with the exception of wireless telecommunications.
[7] Estimates available in appendix A, B, and C of this document.

# 8. IMPACT OF TELECOMMUNICATIONS THROUGHOUT THE TOTAL SENEGALESE ECONOMY

In sum, when considering the aggregate industry revenues and the spill-over indirect effects on the rest of the Senegalese economy, mobile telecommunications and fixed broadband have a contribution of 10.80% on Senegal's GDP.

**Table 10. Direct and indirect contribution of telecommunication to the Senegalese´s economy**

| | | Million US$ 2016 | In % of GDP |
|---|---|---|---|
| Direct contribution (Industry Gross revenues) | Fixed telecommunications | $ 594 (*) | 4.05 % |
| | Mobile telecommunications | $ 697 (*) | 4.75 % |
| | Total | $ 1,291 | 8.79 % |
| Indirect contribution | Mobile telecommunications | $ 110 | 0.75 % |
| | Fixed broadband | $ 185 | 1.26 % |
| | Subtotal | $ 295 | 2.01 % |
| Total | | $ 1,586 | 10.80 % |
| Senegal GDP | | $ 14,684 | 100 % |

(*) 2015

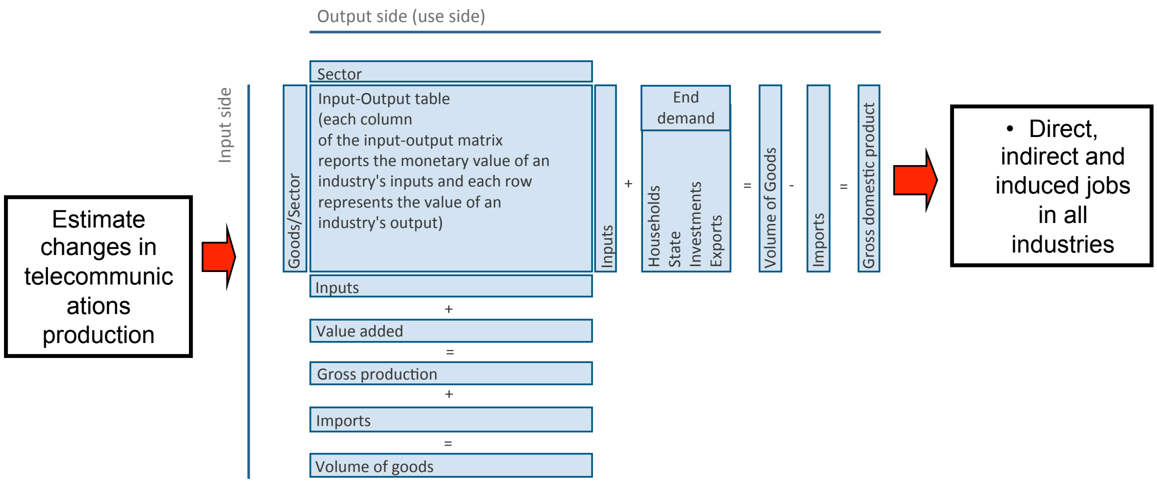
*Source: International Telecommunications Union; GSMA; Telecom Advisory Services analysis*

The importance of the telecommunications sector can also be validated when looking at the number of jobs it generates. In 2015, the sector generated 3,445 direct jobs[8], which represents 0.07% of total Senegalese workforce (this would represent a much higher percentage of total salaries).

Beyond assessing telecommunications total economic impact, it is useful to estimate their impact throughout different sectors of the economy. For this purpose, we rely on input-output analysis (Katz, 2012; Katz et al, 2008; Katz et al., 2009; Katz, 2013; Kingdom of Saudi Arabia, 2017). This economic technique, which measures the interdependence of an economy's various productive sectors, has been used to estimate what the impact might be as a result of changes in output of the telecommunications sector. According to this approach, telecommunications output is defined as a factor of production of other goods and services, creating spill-overs, with significant economic effects. The structure of an input/output table comprises horizontal rows describing how an industry's total output is divided among various production processes and final consumption, and each column denotes the combination of productive resources used within one industry (see Figure 3).

[8] The UIT reports that all telecommunications operators had 3,445 employees in 2015

**Figure 3. Example of an Input / Output Table**




*Source: Katz (2012)*

Each country has a specific table to reflect the particularities of its economy. For this purpose, relying on data from the Global Trade Analysis Project (GTAP) from Purdue University, we developed an Input / Output (I/O) matrix for Senegal that can estimate on the basis of industries interdependence and labor productivities the impact of a change in telecommunications output on sector GDP and employment[9]. Once this was done, the sum of all telecommunications economic impact derived from wireless and fixed broadband was considered to be incremental telecommunications output, triggering not only employment but also incremental downstream output from other non-telecom industries.

For purposes of the Senegal estimation, the sum of the increase in economic contributions from wireless telecommunications (including voice and data) and fixed broadband was considered (from table 10), amounting to US$ 295 million.

According to Senegal's Input / Output matrix[10], an impact of US$ 295 million in telecommunications output would be broken down in the following sectors (see table 11).

[9] This technique has been used by researchers at the World Bank to estimate the economic effects of infrastructure deployment.
[10] The I-O matrix was developed from the Global Trade Analysis Project Database (GTAP) calculated for the year 2011.

**Table 11. Sector impact of GDP increase in telecommunications output**

| Sector | Percentage of the impact | Sector weight on GDP (*) | Amount (US$ million) | Amount (% GDP) |
|---|---|---|---|---|
| Agriculture | 1.15% | 24.61% | $3.39 | 0.02% |
| Textiles and apparel | 1.86% | 1.68% | $5.49 | 0.04% |
| Wood, paper, petroleum, rubber and plastic products | 10.73% | 8.34% | $31.65 | 0.22% |
| Metal products | 0.09% | 3.46% | $0.27 | 0.00% |
| Machinery and equipment | 5.44% | 1.66% | $16.05 | 0.11% |
| Electricity, gas and water | 10.43% | 3.72% | $30.77 | 0.21% |
| Construction | 0.08% | 8.55% | $0.24 | 0.00% |
| Trade | 19.06% | 14.08% | $56.23 | 0.39% |
| Transportation | 4.62% | 4.75% | $13.63 | 0.09% |
| Financial services | 38.02% | 7.88% | $112.16 | 0.76% |
| Other services | 8.52% | 21.28% | $25.13 | 0.18% |
| Total | 100% | 100% | $295.00 | 2.01% |

*(*) Excluding communication sector*
*Source: Telecom Advisory Services Analysis & Global Trade Analysis Project Database (GTAP)*

As the data on table 11 indicates, the most important downstream effects of telecommunications on the Senegal GDP are concentrated in the financial services, and trade sectors. This breakdown on downstream effects might not be consistent yet with policy guidelines such as Digital Senegal 2025 priority sectors (agriculture, health care, education, trade and public sector). Nevertheless, while the priority sectors defined in the strategy might be a long-term objective, the data in table 10 represents the current state of affairs.

Along those lines, it is interesting to note that 38% of downstream effects are concentrated in financial services. This value is revealing in so far that the telecommunications industry appears to be a key input in promoting efficiency in economic transactions and, more importantly, in financial inclusion. With a bankarisation rate that is extremely low (16%[11]), the telecommunications industry acts as a critical enabler of financial transactions.[12] For example, Orange Money provides money transfer services for over 1,000,000 users.

The second most important downstream effect is detected in the trade sector. Beyond the importance of telecommunications in enhancing the efficiency of commerce, this value (19.06% of downstream contribution) is related to the importance that this sector has in the overall Senegalese economy.

Finally, an important spill-over effect is also detected in manufacturing industries (18% in the aggregate). This is a particularly important point relating back to the priority sectors defined in the Senegal Digital 2025 plan. While manufacturing is not

[11] BCEAO. *Note d'Information du T4, 2014.*
[12] It is interesting to point out that estimates for annual benefit of services such as Orange Money amount to €92.1 million (or US$ 113 million). See Goodwill Management (2017). *Evaluation de l'Empreinte Economique d'Orange sur l'économie du Sénégal.*

identified as a priority sector, it should be noted that it benefits significantly from the telecommunications input in terms of supply chain and distribution efficiencies.

## 9. CONCLUSIONS

The policy implications of these results are fairly significant. As stated by the Senegalese government, the ICT sector represents 5.1% of the GDP.[13] Along those lines, industrial policies that foster development of this sector are fairly critical for the future development of the country (a fact recognized in the Digital Senegal 2025 Strategy).[14] This study contributes to shedding some light on the direction to be taken by some of the policies.

First and foremost, maximization of economic impact of telecommunications in emerging countries is driven at this time by mobile broadband. With the growth in mobile telephony penetration, this technology has reached a threshold after which its economic impact starts to decline. On the other hand, fixed broadband, while registering some economic impact, it is still far for achieving a big contribution, partly because mobile broadband appears at this stage to be the most powerful driver of the economic impact of telecommunications. From this standpoint, governments should aim at deploying all policy instruments aimed at stimulating mobile broadband network deployment and service adoption for purposes of maximizing economic effects. These incentives should range from a reduction of taxes and contributions beyond conventional fiscal instruments to a spectrum policy that facilitates access to this resource by service providers.

Secondly, from a spill-over standpoint, as one might intuitively project, the service sector (primarily trade, and financial services) are high beneficiaries of mobile broadband. However, it is also apparent that certain manufacturing sectors, as well as other network industries (like electricity, gas and water) are starting to receive an important share of spill-over effects. In that sense, forward-looking digital agendas should at the same time support adoption in business services which benefit the most from adopting broadband, those that account for a significant part of aggregate GDP, and social services, such as education and public administration.

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[13] Edjo, M. (2018). *Sénégal: en 2017, le secteur des TIC a contribué à hauteur de 5,1% dans le PIB.* Retrieved at:
https://www.agenceecofin.com/gouvernance-economique/1601-53537-senegal-en-2017-le-secteur-des-tic-a-contribue-a-hauteur-de-5-1-dans-le-pib.
Also, the ITU indicates that the sector generated revenues for US$ 1,291 million (8.79% of Senegal's GDP)

[14] Telecommunications Development Study Groups. ITU-D Study Group 1 and 2 Rapporteur Group Meetings. Geneva, 9-18 January 2017 and 18-27 January 2017.

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## Appendix A: Calculation of Mobile Telecommunications Contribution to GDP in Senegal (2009-2016)

| Item | Factor | Value | Source and / or estimation formula |
|---|---|---|---|
| 1 | Annual contribution of unique mobile subscribers to GDP growth (for a 10% increase in additional penetration). Includes mobile broadband | 1.86 % | Coefficient resulting from structural model |
| 2 | Unique mobile subscribers/population, 4Q 2016 | 49.97 % | GSMA Intelligence |
| 3 | Unique mobile subscribers/population, 4Q 2009 | 33.61 % | GSMA Intelligence |
| 4 | Compound Annual Growth Rate (CAGR) of mobile unique subscribers/population | 8.98 % | (Unique mobile subscribers/population 2016/2009)^(1/7 years)-1 |
| 5 | Annual impact of mobile telecommunications on GDP | 0.77 % | (Annual impact/10) * (CAGR Unique mobile subscribers/population) |
| 6 | CAGR GDP (2009-2016) | 4.43 % | (GDP 2016/GDP 2009) ^ (1/7 years)-1 |
| 7 | Percent contribution of mobile telecommunications to GDP growth | 17.46 % | Annual impact of unique mobile subscribers on GDP / CAGR GDP (2009-2016) |
| 8 | Incremental GDP growth (2016/2009) | US$ 4,404 M | GDP 2016- GDP 2009 |
| 9 | Total impact of mobile telecommunications on incremental GDP growth | US$ 769 M | Incremental GDP (2016/2009) * % contribution of mobile telecommunications to GDP growth |
| 10 | Annual impact of mobile telecommunications on GDP | US$ 110 M | Total impact /7 years |

*Source: Telecom Advisory Services analysis*

## Appendix B. Calculation of Mobile Broadband Contribution to GDP in Senegal (2012-2016)

| Item | Factor | Value | Source and / or estimation formula |
|---|---|---|---|
| 1 | Annual contribution of mobile internet to GDP growth (for a 10% increase in additional penetration) | 1.04 % | Coefficient resulting from structural model |
| 2 | Unique Mobile Internet Subscribers/population, 4Q 2016 | 20.51 % | GSMA |
| 3 | Unique Mobile Internet Subscribers/population, 4Q 2012 | 14.04 % | GSMA |
| 4 | Compound Annual Growth Rate (CAGR) of unique mobile internet subscribers/population | 9.94 % | (Unique mobile internet subscribers/population 4Q 2012/4Q 2016) ^(1/4 years)-1 |
| 5 | Annual impact of mobile internet on GDP | 1.03 % | (Annual impact)/10 * (CAGR Unique Mobile Internet Subscribers/population) |
| 6 | CAGR GDP (2012-2016) | 5.17 % | (GDP 2016/ GDP 2012)^(1/4 years)-1 |
| 7 | Percent contribution of mobile internet to GDP growth | 20.00 % | Annual impact of mobile internet on GDP / CAGR GDP (2012-2016) |
| 8 | Incremental GDP growth (2012-2016) | US$ 3,075 M | GDP 2016- GDP 2012 |
| 9 | Total impact of mobile internet on incremental GDP growth | US$ 615 M | Incremental GDP (2016/2012) * % contribution of mobile internet to GDP growth |
| 10 | Annual impact of mobile internet on GDP | US$ 154 M | Total impact / 4 years |

*Source: Telecom Advisory Services analysis*

## Appendix C. Calculation of Fixed Broadband Contribution to GDP in Senegal (2004-2016)

| Item | Factor | Value | Source and / or estimation formula |
|---|---|---|---|
| 1 | Annual contribution of fixed broadband to GDP growth (for a 10% increase in additional penetration) | 0.68 % | Coefficient resulting from structural model |
| 2 | Fixed broadband penetration, mean 2016 | 5.82% | UIT & ARTP |
| 3 | Fixed broadband penetration, mean 2004 | 0.39% | UIT & ARTP |
| 4 | Compound Annual Growth Rate (CAGR) of fixed broadband penetration | 25.18 % | (Fixed broadband penetration 2016/2004) ^(1/12 years)-1 |
| 5 | Annual impact of fixed broadband on GDP | 1.72 % | (Annual impact)/12 * (CAGR fixed broadband penetration) |
| 6 | CAGR GDP (2004-2016) | 5.16 % | (GDP 2016/ GDP 2004)^(1/12 years)-1 |
| 7 | Percent contribution of fixed broadband to GDP growth | 33.42 % | Annual impact of fixed broadband on GDP / CAGR GDP (2004-2016) |
| 8 | Incremental GDP growth (2016-2004) | US$ 6,652M | GDP 2016 - GDP 2004 |
| 9 | Total impact of fixed broadband on incremental GDP growth | US$ 2,223 M | Incremental GDP (2016/2004) * % contribution of fixed broadband to GDP growth |
| 10 | Annual impact of fixed broadband on GDP | US$ 185 M | Total impact / 12 years |

*Source: Telecom Advisory Services analysis*