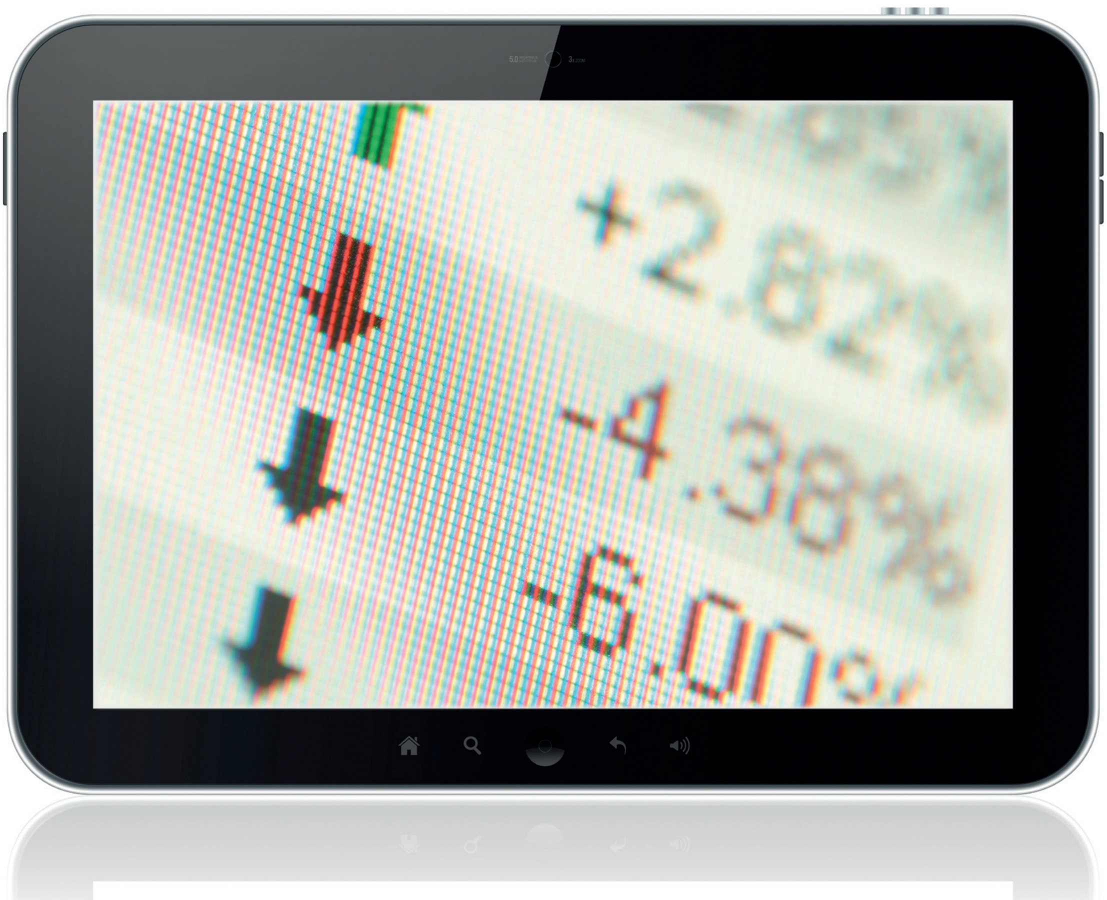
What is the impact of mobile telephony on economic growth?

A Report for the GSM Association



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Foreword

The mobile telecommunications sector continues to offer unprecedented opportunities for economic growth in both developed and developing markets, and mobile services have become an essential part of how economies work and function.

In developed markets, recent years have seen booming usage in mobile data services accessed via smartphones, tablets and dongles. Mobile data has changed consumer expectations for wireless services products and has transformed the way in which people connect and work, which has the potential to further impact economic development. Against this backdrop, Deloitte, the GSMA and Cisco have joined forces to measure the impact of next generation mobile services on economic growth. The resulting analysis provides the first estimates of the impact of mobile data usage in developed markets, employing information on mobile data provided for this study by Cisco Systems based on their Visual Network Index (VNI).

For developing markets, basic mobile services still dominate and mobile data is the next wave of advancement. As such, this study considers the key role that adoption of this technology has played in enhancing economic growth through increasing productivity.

We intend to run this analysis on an annual basis as usage of mobile data services grows and more countries are included in the analysis, and we would welcome comments on our approach and conclusions.
We look forward to your feedback as we continue to explore this fascinating topic.

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The impact of mobile telephony on economic growth: key findings

The incremental benefits of next generation mobile telephony services, such as 3G technology and mobile data services, on economic growth have not been fully explored yet.

This study covers this gap:

- Measuring the impact of substituting basic 2G connections with more advanced 3G connections on economic growth.

- Providing the first reliable estimates of the impact of mobile data usage on economic growth in developed markets, employing information on mobile data provided for this study by Cisco Systems based on their Visual Network Index (VNI).

What is the impact of 3G penetration on GDP growth?
As technology develops, mobile services have the potential to impact economic development further through the provision of high value 3G and 4G data services accessed via smartphones, tablets and dongles that deliver mobile data services to businesses and consumers.

The analysis of data on penetration in a panel of 96 developed and developing markets quantifies for the first time a positive effect on economic growth of consumers substituting a 2G connection with a 3G connection:

- For a given level of total mobile penetration, a 10 per cent substitution from 2G to 3G penetration increases GDP per capita growth by 0.15 percentage points.

What is the impact of mobile data on GDP growth?
The increase in 3G connections, supported by the proliferation of data-enabled devices that allow mobile internet connectivity, has led to a massive growth in the use of mobile data. To date, investigation of the economic impact of this transformation has been limited by data availability. This study uses data from Cisco's VNI Index for 14 countries to consider this question and finds a strong relationship between usage of mobile data per each 3G connection and economic growth:

- A doubling of mobile data use leads to an increase in the GDP per capita growth rate of 0.5 percentage points.

What is the impact of mobile telephony on productivity in developing markets?
While the effects of mobile telephony have more fully materialised in more developed markets, mobile telephony continues to deliver strong benefits to developing markets. This study has measured the impact of 'simple' mobile penetration on a country's Total Factor Productivity, a measure of economic productivity that often reflects an economy's long-term technological dynamism:

- A 10 per cent increase in mobile penetration increases Total Factor Productivity in the long run by 4.2 percentage points.

What is the impact of mobile telephony on economic growth?

The mobile telecom sector continues to offer unprecedented opportunities for economic growth in both developing and developed markets, and mobile communication services have become an essential part of how economies work and function.

A series of studies have found a link between mobile penetration and economic growth. Mobile phones have improved communication, social inclusion, economic activity and productivity in sectors such as agriculture, health, education and finance. As technology develops, mobile services have the potential to further impact economic development through the provision of high value 3G and 4G data services accessed via smartphones, tablets and dongles that deliver mobile data services to businesses and consumers. The relationship between economic growth, 3G telephony and mobile data use has not been explicitly explored yet, and this paper seeks to address this gap.

In order to quantify such impacts, Deloitte and the GSM Association have sought to estimate a series of econometric models considering the extent to which changes in the availability and use of mobile services have affected economic growth and productivity. This analysis extends previous work in the area, and also provides the first estimates of the impact on GDP per capita growth of consumers substituting a 2G connection with a 3G connection and the impact of increasing usage of mobile data per each 3G connection, based on data from Cisco Systems.

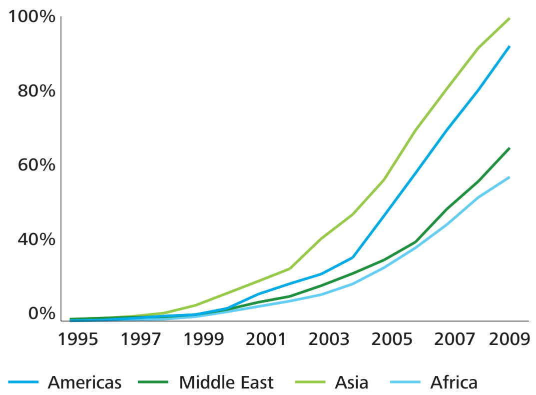
The results of this analysis are summarised below, with details reported in the appendices to this report.

1. Background

Mobile telephony has transformed the way in which consumers and businesses operate in developing markets. As fixed lines often remain undeveloped and unavailable to the majority of the population in developing markets, mobile services have often become the universal providers of communications services.

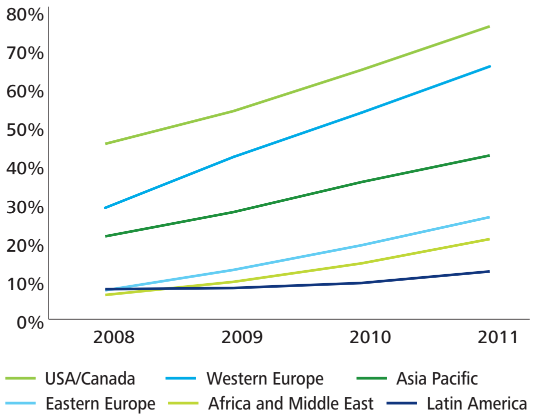
Total mobile penetration has more than doubled in all regions of the world since 2005, which can be attributed to numerous factors including a fall in handset and usage costs and an improvement in service quality and network coverage. These significant penetration increases have made basic mobile services, i.e. voice, texts and basic text-related services available to billions of people across all income levels.

Figure 1. Mobile penetration by region (1995-2009)



Source: World Bank. The figure is based on a simple country average by region of mobile penetration in a set of 89 developing markets.

Figure 2. 3G penetration rates across regions (2008-2011)



Source: Wireless Intelligence. The figure is based on a simple country average by region of 3G penetration in a set of 96 developed and developing markets.

Availability of mobile services generates numerous economic benefits to a country's economy. Mobile telephony positively affects the supply side of the economy through the operations undertaken by mobile operators and actors in the wider mobile ecosystem, including providers of network services, providers of other support and commercial services, and the network of formal and informal points of sale throughout each country.

These positive economic impacts of mobile telephony services have been quantified by Waverman et al (2005), who concluded that 10 more mobile phones per 100 people would increase GDP per capita growth by up to 0.6 percentage points. Studies focussing on developing countries, found this impact to be larger, between 0.8 and 1.2 percentage points.

While these studies focussed on the impact of basic mobile telephony services, the objective of this study is primarily to assess whether the effect of mobile telephony on economic growth is still strong and persistent in the current context of evolving technology and increased penetration and use.

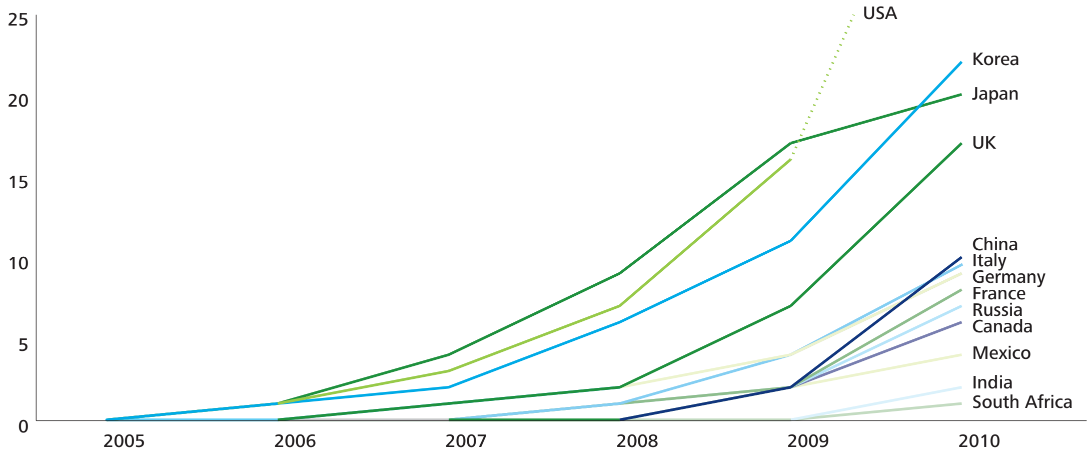
3G penetration, measured as number of 3G connections per 100 people, has increased significantly worldwide in recent years, reaching over 60% in Western Europe and over 90% in the USA in 2011. This growth is supported by the availability of devices such as phones with 3G capabilities, smartphones and tablets, which have proliferated in recent years.

The increase in 3G connections, supported by the proliferation of data-enabled devices that allow mobile internet connectivity, has led to massive growth in mobile data usage.

According to Cisco Systems, who for this study have provided their Visual Networking Index data, total mobile data usage has more than doubled on average every year from 2005 to 2010 in each country in the sample. In the USA, mobile data usage grew on average by 400% a year between 2005 and 2010, while in the Western European countries considered, it grew by 350%. In countries such as India, Brazil and China total usage has also more than doubled every year on average since mobile data was introduced.

Mobile data usage per each 3G connection also more than doubled on average every year in the period 2005 to 2010 in each country in the sample, despite the considerable increase in 3G connections. In the USA mobile data usage per 3G connection grew on average by more than 300% a year between 2005 and 2010, while in the Western European countries considered it grew by 170% over the same period.

Figure 3. Total mobile data usage, PB/month (2005-2010)



Source: Cisco Systems. In 2010, in the USA, total mobile data usage was approximately 40 PB/month (PB = Petabytes = 10^{15} bytes)

For a given level of total mobile penetration, a 10 per cent substitution from 2G to 3G penetration increases GDP per capita growth by 0.15 percentage points.

2. What is the impact of 3G penetration on GDP growth?

As mobile telephony markets become more mature, the positive impacts of basic mobile voice and text services on growth and productivity are achieved. Whereas the impact of 2G services is significant, as more developed 3G technology replaces 2G, an incremental economic impact is observed. Differential economic growth is supported as these technology changes allow consumers and businesses to benefit from high value wireless data and content services.

As such, in developed markets where penetration has long exceeded 100%, as well as in the higher-income consumer and business user segments in developing markets, a substitution effect has taken place in mobile telephony whereby mobile users previously consuming standard services have been acquiring 3G connections. The impact of this transition on GDP growth has not been quantified yet.

While this substitution effect does not necessarily increase total mobile penetration, an econometric analysis of the relationships between 3G connections and economic growth in developed and developing markets finds that increases in penetration of 3G services generate significant economic benefits.

The econometric relationship between 3G penetration and GDP per capita growth

Approach

This study measures the effect of consumers substituting a standard 2G mobile connection with a 3G connection on economic growth. Including both total mobile penetration and 3G penetration in the model allows interpreting the coefficient of the 3G penetration variable as the impact of increasing 3G penetration keeping all other factors equal, including total mobile penetration. The econometric approach follows previous work by Andrianaivo and Kpodar (2011) and Lee, Levendis and Gutierrez (2009) on the impact of mobile penetration on GDP per capita growth. The potential endogeneity of mobile penetration and 3G penetration is addressed by employing the Arellano-Bond estimator, where mobile penetration and 3G penetration are instrumented using their own lags.

Data

A panel of 96 countries is used. Data is measured across a 4 year (2008-2011) period. Years before 2008 are not included in the analysis due to the late development 3G networks in many countries.

Equation estimation

The annual growth rate of real GDP per capita is expressed as a function of the lag of real GDP per capita, 3G penetration, mobile penetration and a set of determinants of growth. These are: government expenditure, trade volumes, aggregate investment and labour. All variables have been transformed in logarithmic form.

Results

For a given level of mobile penetration, across the whole sample of countries considered, if countries had a 10% higher 3G penetration between 2008 and 2011, they would have experienced an increase in the average annual growth rate of GDP per capita by 0.15 percentage points.

These results imply that countries with a proportionately higher share of 3G connections enjoy an improved GDP per capita growth compared to countries with comparable total mobile penetration but lower 3G penetration.

For a similar absolute increase in the number of 3G connections, countries with lower 3G penetration experience a higher impact on GDP per capita growth.

This relationship is best demonstrated by the use of examples of countries with different levels of 3G penetration.

- In Indonesia, where the average penetration of 3G services was 10% over 2008-2011, 10 more 3G connections per 100 connections (a 100% increase from the actual 3G penetration level of 10%), would have increased the GDP per capita growth rate by 1.5 percentage points.

- In Turkey, where the average penetration of 3G services was 25% over 2008-2011, 10 more 3G connections per 100 connections (a 40% increase from the actual 3G penetration level of 25%) would have generated an additional growth in GDP per capita of 0.6 percentage points.

- In USA, where the average 3G penetration was 42% over 2008-2011, 10 more 3G connections per 100 connections (a 24% increase from the actual 3G penetration level of 42%), would have increased the GDP per capita growth rate by 0.4 percentage points.

A doubling of mobile data use leads to an increase in GDP per capita growth of 0.5 percentage points

3. What is the impact of mobile data on GDP growth?

Growth in mobile data consumption has the potential to transform the way in which consumers and businesses operate and communicate, and as such increase economic growth through increased productivity effects.

However, given the limited data availability, this impact has not been quantitatively examined. This study uses detailed information provided by Cisco Systems from their VNI to address this issue. The VNI provides data on the level of mobile data usage between 2005 and 2010 in 14 countries for which historical disaggregated data is available. For these countries, mobile data usage per each 3G connection can be calculated.

For the first time, this study finds that there is a positive relationship between the amount of mobile data used by each 3G connection and increases in economic growth.

The results indicate that mobile data usage per 3G connection has a positive effect on the growth rate of GDP per capita. This effect grows linearly with the initial level of data usage per 3G connection in the country: countries with a higher average level of mobile data consumption per each 3G connection experience a larger impact on GDP per capita growth from increasing this consumption.

Countries such as Russia, the UK and South Korea, which are characterised by a higher level of data usage per 3G connection, experience an increase in GDP per capita growth of up to 1.4 percentage points. The effect is more limited for countries that are still developing mobile data usage, e.g. India, China, South Africa and Mexico, supporting scope for further growth.

The econometric relationship between mobile data usage and GDP per capita growth

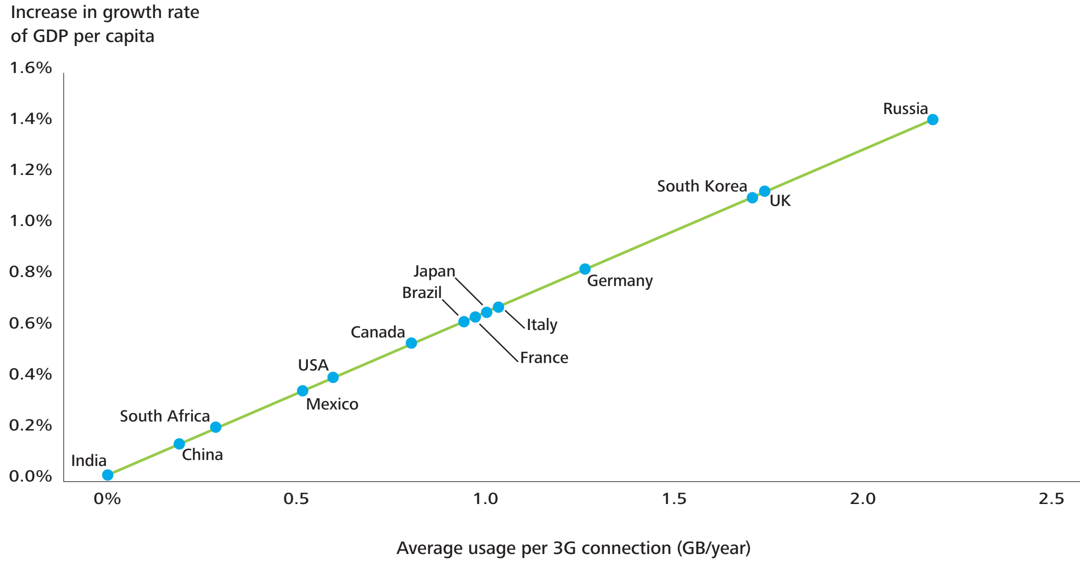
Approach
The econometric approach used is the dynamic panel data estimation method introduced by Arellano and Bond. This technique addresses the potential endogeneity of mobile penetration and mobile data usage by instrumenting them using their own lags. This technique also best exploits the information contained in the dataset such as the cross country variation in the sample and the variation within countries across time.

Data
The dataset employed for this study consists of the 14 countries for which data from Cisco Systems is available: Brazil, Canada, China, France, Germany, India, Italy, Japan, Korea, Mexico, Russia, South Africa, United Kingdom, USA.

Equation estimation
The annual growth rate of real GDP per capita is expressed as a function of the lag of real GDP per capita, mobile penetration, mobile data usage per 3G connection, and a set of determinants of growth such as aggregate investment and labour force. Logarithms of all variables are used, with the exception of mobile penetration and mobile usage, to which has been applied the inverse hyperbolic sine transformation. An additional parameter is also included within each inverse hyperbolic sine transformation to accommodate more general forms of non-linearity.

Results
On average, across the sample of 14 countries considered, if countries doubled their consumption of mobile data per 3G connection between 2005 and 2010, they would have experienced a growth rate of GDP 0.5 percentage points higher each year.

Figure 4. Effect of doubling mobile data usage per 3G connection on GDP per capita growth



Source: Deloitte analysis

A 10% increase in mobile penetration increases Total Factor Productivity in the long run by 4.2 percentage points.

4. What is the impact of 'basic' mobile telephony on productivity in developing markets?

The development of data services described above can be expected to flow into the developing world at a rapid rate. However, in previous years basic voice has dominated the use of mobile telephony in these countries.

There is a long literature showing the link between mobile penetration and economic growth. The premise of this work is that mobile telephony generates a positive impact on workers productivity, which in turn impacts business productivity through routes such as improved information flows on prices, quantities and quality; reduced travel time and costs; improved the efficiency of mobile workers; improved job search and promotion of entrepreneurialism. Investigation of such productivity impacts has tended to be of a qualitative nature.

In order to bridge this gap in understanding, this study considers the impact of mobile penetration on countries Total Factor Productivity (TFP), a measure of economic productivity which accounts for effects in total output not caused by traditionally measured inputs such as capital and labour and that often measures an economy's long-term technological dynamism. While the relationship between GDP and TFP varies by country, increases in TFP lead to increases in GDP through a better utilisation of capital and labour inputs, which therefore become more productive.

Using a sample of developing countries and recent figures on penetration, this study finds that mobile phone penetration has a significant and positive effect on TFP.

The econometric relationship between mobile penetration and Total Factor Productivity

Approach

The econometric approach follows previous work by Thompson and Garbacz (2007). The positive effects of mobile penetration on productivity are considered using TFP as a measure of productivity. The TFP impact of an increase in mobile penetration is measured through Stochastic Frontier Analysis (SFA), which is an econometric technique used to compare productivity across a panel of countries.

The SFA assumes the existence of a theoretical production possibility frontier that each country could achieve for a given amount of inputs such as labour and capital. It allows separating the true country-specific inefficiency from the random shocks to GDP that affect an economy, thereby highlighting the factors that can improve a country's production frontier. SFA allows testing whether countries with higher levels of mobile penetration are associated with lower levels of inefficiency, i.e. with higher productivity.

Data

A panel of 74 countries is employed for which suitable data is available. The model variables are measured across the period 1995-2010.

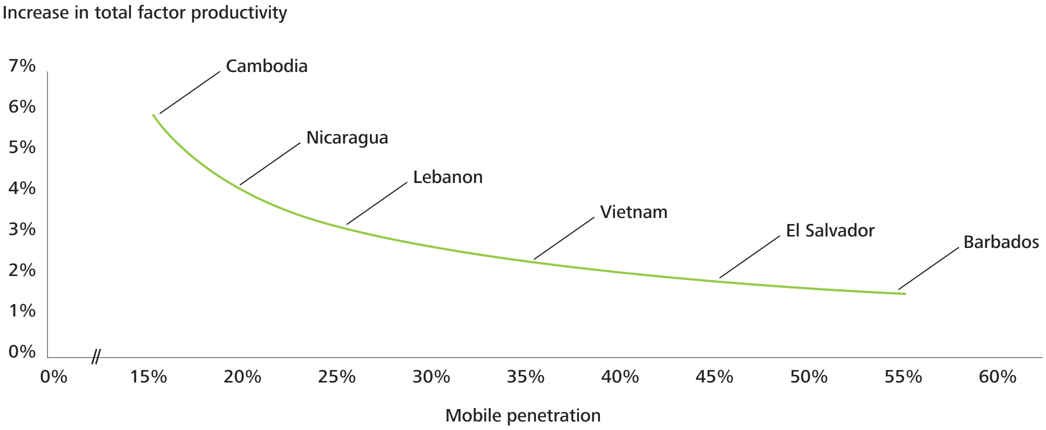
Equation estimation

A two-step approach is taken. First, the relationship between GDP and TFP is measured. TFP enters the GDP production function as a multiplicative term, enhancing the GDP output for a given level of labour and capital. Mobile penetration contributes to increasing TFP. Second, a country's inefficiency term is regressed against mobile penetration to test whether higher mobile penetration contributes to improving a country's productivity.

Results

Overall, across the whole sample of countries considered, if countries had a 10% higher mobile penetration between 1995 and 2010, they would have experienced on average in the long run a TFP increase of 4.2 percentage points.

Figure 5. Marginal effect of a 10% increase in mobile penetration on productivity



Source: Deloitte analysis

5. Conclusions

This study finds that the contribution of mobile telephony to promoting economic growth is strong and materialises across both developed and developing markets.

The impact of 2G services is important, increasing productivity significantly. Perhaps more importantly, the adoption of 3G technology and use of mobile data are found to have significant impacts on economic growth. This input has the potential to be felt globally as advanced mobile services proliferate.

To achieve the benefits highlighted in this study, governments should focus on increasing 3G penetration in markets where mobile data services are still developing by encouraging substitution of basic mobile services with more advanced 3G connections and supporting a fast increase of mobile data consumption.

Appendix A: 3G penetration and economic growth

This appendix presents the details of the econometric estimation carried out in order to assess the impact of 3G penetration on economic growth.

A.1 Objectives and background

As mobile markets mature and new advanced services are developed, 3G penetration increases. Increases in 3G penetration could essentially be caused by two distinct factors: first, they can be due to a 'substitution effect', associated with consumers that previously owned a standard 2G mobile connection switching to a 3G connection. This mechanism increases 3G penetration but not total mobile penetration in the country. Second, increases in 3G penetration could be caused by an 'incremental effect', e.g. consumers that previously did not have any mobile connection acquiring a 3G connection. This 'incremental effect' could be also associated with consumers deciding to acquire a tablet or a dongle and a separate 3G connection to support these devices. This effect would contribute to increasing overall mobile penetration.

This study aims to estimate the impact on GDP per capita growth of the first effect and to test whether, for given levels of total mobile penetration, countries with a proportionately higher share of 3G connections are expected to experience an improved GDP per capita growth compared to other countries with comparable total mobile penetration but a lower share of 3G.

A.2 The dataset employed

Table 1 provides a list of the countries included in the sample.

Table 1. List of countries included in the analysis of 3G penetration and GDP per capita growth

Region	Countries
Western Europe	Austria; Belgium; Cyprus; Denmark; Finland; France; Germany; Greece; Iceland; Ireland; Italy; Luxembourg; Malta; Netherlands; Norway; Portugal; Spain; Sweden; Switzerland; United Kingdom.
Eastern Europe	Azerbaijan; Belarus; Bulgaria; Croatia; Czech Republic; Estonia; Georgia; Hungary Kazakhstan; Kyrgyz Republic; Latvia; Lithuania; Macedonia; Moldova; Poland; Romania; Russia; Slovak Republic; Slovenia; Tajikistan; Turkey; Ukraine; Uzbekistan.
Africa and Middle East	Botswana; Egypt; Ghana, Israel; Kenya; Lesotho; Mauritania; Mauritius; Morocco; Mozambique; Namibia; Saudi Arabia; South Africa; Sudan; Syria; Tanzania; Uganda.
Asia Pacific	Bangladesh; Cambodia; China; Hong Kong; India; Indonesia; Japan; Korea, Rep.; Macao; Malaysia; Mongolia; Nepal; Philippines; Singapore; Sri Lanka; Thailand; Viet Nam.
Americas	Argentina; Bolivia; Brazil; Canada; Chile; Colombia; Dominican Republic; Ecuador; El Salvador; Guatemala; Honduras; Mexico; Nicaragua; Panama; Paraguay; Peru; United States; Uruguay; Venezuela.

Source: Deloitte analysis

Only countries for which data was available for all variables and time periods of interest have been retained in the sample. This generated a panel of 96 countries measured across a period of four years (2008-2011).[1] Years before 2008 have not been included in the analysis due to the late development 3G networks in a considerable number of countries. Including years before 2008 would have required a substantial reduction in the sample of countries.

1 Data on total mobile penetration and 3G penetration were available for all years. A subset of the other variables has been extrapolated from 2010 to get the related 2011 figures.

Table 2 below presents the variables included in the econometric model with their definitions.

Table 2: Variables used in the analysis of 3G penetration and GDP per capita growth

Variables	Description
GDP per capita	Real GDP per capita (constant USD).
Trade/GDP	Annual trade volume as a proportion of GDP (proxy for the 'degree of openness' of a country to international trade).
Investment/GDP	Annual share of aggregate investment to GDP.
Labour	Total labour force.
GovExp/GDP	Annual government consumption expenditure for goods and services as a share of GDP.
MobPen	Level of mobile penetration, measured in terms of mobile phone subscribers per 100 population.
3GPen	Level of 3G penetration, measured in terms of 3G subscribers per 100 population.

Source: World Bank's World Development Indicators[2] and Wireless Intelligence[3]

In order to better understand the dynamics of the variables of interest, Table 3 below presents the average mobile and 3G penetration as well as the growth rate of GDP per capita for each of the regions of the sample.[4]

Table 3. Mobile penetration, 3G penetration and growth rate of GDP per capita (2008-2011)

Region	Average GDP per capita growth	Average mobile penetration	Average 3G penetration
Western Europe	0.7%	131%	48%
Eastern Europe	3.3%	110%	16%
Africa and Middle East	3.2%	78%	13%
Asia Pacific	6.2%	93%	32%
Latin America	4.2%	96%	9%
USA/Canada	1.5%	84%	60%
Total (full sample)	**3.4%**	**102%**	**25%**

Source: Deloitte analysis based on World Bank and Wireless Intelligence data

The table indicates that, among the sample from 2008 and 2011, Africa is the region with the lowest average mobile penetration, while Latin America is the region with the lowest 3G penetration during the same period. Western Europe ranks first in terms of total mobile penetration while 3G penetration is highest in North America. The Eastern European region ranks second in terms of average mobile penetration but lags behind all regions but Africa and Latin America in terms of development of 3G networks.

2 Available from: http://data.worldbank.org/indicator.

3 Available from: http://www.wirelessintelligence.com (only for subscribers).

4 The average mobile and 3G penetration by region is calculated as the simple average across the countries included in this study.

A.3 Our approach

A dataset of 96 countries was constructed using publicly available data from the World Bank's World Development Indicators.[5] Additionally, information on total mobile penetration and 3G penetration was obtained from the Wireless Intelligence database.[6]

The econometric analysis studies how the annual growth rate of real GDP per capita is affected by 3G penetration and by a set of determinants of growth such as real GDP per capita in previous years, government expenditure, trade volumes, and aggregate investment.

Capturing the impact of 3G penetration on GDP per capita growth presents a number of challenges. Economic theory suggests the existence of a reverse causality issue between these variables: higher levels of 3G penetration are expected to lead to higher GDP per capita growth, but also higher growth is expected to be associated with faster development of mobile telecommunications infrastructure. Due to this complex relationship, isolating the causal impact of 3G penetration on GDP per capita growth requires careful econometric analysis.

The approach of this study follows the work conducted by Andrianaivo and Kpodar (2011) and Lee, Levendis and Gutierrez (2009) which are among the few panel data studies that focus on the effects of mobile Information and Communication Technologies ('ICT') on economic growth. In these papers, the issue of reverse causality between mobile telecoms expansion and economic growth is addressed by specifying a dynamic panel data model and estimating the parameters using Generalized Method of Moments (GMM) techniques.

A.4 The model

The model specification adopted is a standard endogenous growth model analogous to those employed by Andrianaivo and Kpodar (2011) and Lee, Levendis and Gutierrez (2009):

$$\ln(GDPpercap_{i,t}) - \ln(GDPpercap_{i,t-1}) = \alpha_1 \ln(GDPpercap_{i,t-1}) + \alpha_2 \ln(GDPpercap_{i,t-2}) + \beta \ln(MobPen_{i,t}) + \delta \ln(3GPen_{i,t}) + X'_{i,t}\Gamma + \eta_i + \varepsilon_{i,t}$$

equation 1

$$\text{where } X_{i,t} \text{ includes: } \ln\left(\frac{GovExp}{GDP}_{i,t}\right), \ln\left(\frac{Trade}{GDP}_{i,t}\right), \ln\left(\frac{Investment}{GDP}_{i,t}\right), \ln(Labour_{i,t})$$

η_i is a country specific effect

On the left hand side of the equation is the annual growth rate of real GDP per capita, which is expressed as a function of the lag of real GDP per capita, 3G penetration, mobile penetration and a set of determinants of growth. These are: government expenditure, trade volumes, aggregate investment and labour.[7] All variables are expressed in logarithmic form.[8]

Proxies for human capital such as primary school education are not particularly informative about differences in human capital across different countries, as many countries are already close to a 100% primary school completion rate. Many studies (especially on developed countries) report an insignificant (or even negative) impact of human capital/education on GDP; a potential explanation is indeed the fact that 'primary school education' does not have enough cross-section variation and does not work very well as a proxy for human capital. One could consider the levels of secondary or tertiary education, but this data is rarely available for all countries. For this reason, proxies for human capital have not been included in the model.

5 Available from: http://data.worldbank.org/indicator.

6 Available from: http://www.wirelessintelligence.com (only for subscribers).

7 For a detailed description of each variable refer to Table 2.

8 Because there were no observations with zero values for mobile or 3G penetration during the period covered by this section, a simple log-transformation was applied. This is very similar in shape to the asinh transformation adopted in the next appendices and facilitates the interpretation and comparison of the impacts of these two variables (Table 4).

A first regression including only one lag of the dependent variable failed to fulfil the Sargan test for over-identifying restrictions and the Arellano-Bond test for autocorrelation of the error term. The introduction of a second lag of the dependent variable in the model specification allowed fulfilling these post-estimation tests' requirements.

A simple transformation leads to the equation that was modelled:

$$\ln\left(GDPpercap_{i,t}\right) =$$

$$\gamma \ln\left(GDPpercap_{i,t-1}\right) + \alpha_2 \ln\left(GDPpercap_{i,t-2}\right) + \beta \ln\left(\mathrm{MobPen_{i,t}}\right) + X'_{i,t}\Gamma + \eta_i + \varepsilon_{i,t}$$

$$\text{where } \gamma = (1 + \alpha_1) \qquad \text{equation 2}$$

Equation 2 is estimated by applying the two-step linear GMM estimator introduced by Arellano and Bond (1991) on the sample of 96 countries presented in Section A.2. Mobile and 3G penetration are assumed to be contemporaneously endogenous, while all other regressors are assumed to be pre-determined.

A.5 Results

Table 4 below reports the results of the Arellano-Bond estimation of equation 2.

Table 4. Regression results

Econometric results						
Arellano-Bond dynamic panel-data estimation				Number of obs = 192		
				Number of groups = 96		
				Obs per group: avg = 2		
Number of instruments = 44				Wald chi2(8) = 460.88		
				Prob > chi2 = 0.0000		
ln_gdppercap	Coef.	Std. Err.	z	P>|z|	[95% Conf. Interval]	
L1.ln(GDPpercap)	.068107	.0212132	3.21	0.001	.02653	.1096841
L2.ln(GDPpercap)	.0135005	.0242515	0.56	0.578	-.0340317	.0610327
ln_govexp	-.0273462	.020023	-1.37	0.172	-.0665905	.0118981
ln(Inv/GDP)	.0518597	.0082379	6.30	0.000	.0357137	.0680056
ln(Trade/GDP)	.0856448	.0166721	5.14	0.000	.052968	.1183215
ln(Labour)	.6884214	.1194524	5.76	0.000	.4542989	.9225438
ln(MobPen)	.0651293	.0216512	3.01	0.003	.0226936	.1075649
ln(3GPen)	.0150549	.0060068	2.51	0.012	.0032818	.0268279
_cons	-3.081036	1.700629	-1.81	0.070	-6.414207	.2521348

Source: Deloitte analysis

The coefficient on total mobile penetration (0.065) suggests that, in this sample of developed and developing countries, a 10% increase in a country's total mobile penetration would lead to an increase in the average annual growth rate of GDP per capita by 0.65 percentage points. This is consistent with recent related literature: a study[9] by the World Bank finds that a 10% increase in mobile penetration leads to an increase in the growth rate of GDP per capita by 0.6 percentage points in developed markets and by 0.8 percentage points in developing markets. Another related study by Waverman, Meschi and Fuss[10] concluded that this impact could be up to 0.6 percentage points.

The coefficient of the 3G penetration variable (0.015) suggests that, for given level of mobile penetration, a 10% increase in 3G penetration would increase the average annual growth rate of GDP per capita by additional 0.15 percentage points. As such, in addition to the benefits deriving from increases in total mobile penetration, countries with proportionately higher shares of 3G connections are expected to experience a higher GDP per capita growth compared to those with lower shares of 3G.

These results support the view that even in more developed markets, mobile telephony continues to constitute a key driver of growth through the improvement of 3G services.

A.6 Diagnostic tests

Two diagnostic tests are available for dynamic panel data regressions: the Arellano-Bond test for autocorrelation in the error term and the Sargan test for over-identifying restrictions.

The short nature of the panel in this case (4 years) did not allow the former test to be performed. The Sargan test instead is shown in Table 5 below: the result shows no evidence to suggest that the instruments are correlated with the error term, thus justifying their use. This is necessary for the consistency of the estimates.

Table 5. Sargan test of over-identifying restrictions

Sargan test of over-identifying restrictions		
H0: overidentifying restrictions are valid		
chi2(35)	=	43.01542
Prob > chi2	=	0.1656

Source: Deloitte analysis

9 Qiang and Rossotto, with Kimura (2009).

10 Waverman, Meschi and Fuss (2005).

Appendix B: Mobile data usage and economic growth

This appendix presents the details of the econometric estimation carried out in order to assess the impact of mobile data use on economic growth.

B.1 Objectives and background

This study tests the impact of mobile data consumption at country level. Analysis of this impact has not yet been rigorously attempted and this econometric study aims to address this gap. The analysis is based on mobile data usage data at country level provided by Cisco Systems based on their Visual Network Index.[11]

B.2 The dataset employed

The dataset employed for this study consists of 14 countries: Brazil, Canada, China, France, Germany, India, Italy, Japan, Korea, Mexico, Russia, South Africa, United Kingdom and USA. These were the countries for which information on mobile data use was available for the full period 2005-2010 from Cisco Systems.

Table 6 presents the variables included in the econometric model with their definitions.

Table 6. Variables used in the analysis of mobile data usage per 3G connection and GDP per capita growth

Variables	Description
GDP per capita	Real GDP per capita (constant USD).
Labour	Total labour force.
Investment/GDP	Annual share of aggregate investment to GDP.
MobPen	Level of mobile penetration, measured in terms of mobile phone subscribers per 100 population.
DataUsage Total data	usage at country level (GB/year).
3G connections	Number of 3G connections, used as a proxy for the number of mobile data users.
Data usage per 3G connection	Obtained by dividing total data usage at country level by the number of 3G connections.

Source: All variables are from the World Bank's World Development Indicators,[12] except the data on mobile data usage, which was provided by Cisco Systems and the data on mobile penetration and 3G connections, which was extracted from Wireless Intelligence.

B.3 Our approach

The econometric approach undertaken was the dynamic panel data estimation method introduced by Arellano and Bond (1991). The choice of this approach was motivated by two main factors. First, this technique allows the potential endogeneity of mobile penetration and mobile data usage per 3G connection to be addressed by using the lags of these variables as instruments. Second, a panel data technique allows the best exploitation of the information contained in the dataset such as the cross country variation in the sample (at a given point in time, different countries are characterised by different levels of data usage per 3G connection) and the time series variation (for each country, mobile data usage substantially varies over time).

11 Available from: http://www.cisco.com/web/solutions/sp/vni/vni_mobile_forecast_highlights/index.html; Cisco Systems has provided disaggregate historic data on mobile data usage for the purposes of this study.

12 Available from: http://data.worldbank.org/indicator.

B.4 The model

The model specification adopted is the following:

$$\ln(GDPpercap_{i,t}) - \ln(GDPpercap_{i,t-1} =$$
$$\alpha \ln(GDPpercap_{i,t-1}) + \beta \operatorname{asinh}(\theta_1 DataUsePer3Gconn_{i,t}) + \phi \operatorname{asinh}(\theta_2 MobPen_{i,t}) + X'_{i,t}\Gamma + \eta_i + \varepsilon_{i,t}$$

$$\text{where } X_{i,t} \text{ includes: } \ln\left(\frac{Investment}{GDP}_{i,t}\right), ln\left(Labour_{i,t}\right)$$

$$\eta_i = \text{ country specific effect independent across i}$$

equation 3

On the left-hand side of the equation is the annual growth rate of real GDP per capita, which is expressed as a function of the lag of real GDP per capita, mobile penetration, mobile data usage per 3G connection, and a set of determinants of growth such as aggregate investment and labour force.[13] All variables are expressed in logarithmic form with the exception of mobile penetration and mobile usage per 3G connection, which have been transformed according to the inverse hyperbolic sine transformation. An additional parameter has also been included within each of the transformations to accommodate more general forms of non-linearity.[14]

A simple transformation leads to the equation that was estimated:

$$\ln\,(GDPpercap_{i,t}) =$$
$$\gamma \ln\,(GDPpercap_{i,t-1}) + \beta \operatorname{asinh}(\theta_1 DataUsePer3Gconn_{\mathrm{i,t}}) + \phi \operatorname{asinh}(\theta_2 MobPen_{\mathrm{i,t}}) + X'_{i,t}\Gamma + \eta_i + \varepsilon_{i,t}$$

$$\text{where } \gamma = (1 + \alpha)$$

equation 4

eq4 above was estimated on the sample of 14 countries (presented in section B.2) by applying the Arellano-Bond estimator and carrying out a grid search over parameters θ_1 and θ_2 to find the values that minimise the GMM objective function. Mobile penetration and mobile data usage per 3G connection were assumed to be contemporaneously endogenous, while the other regressors were assumed to be pre-determined.

13 For a detailed description of each variable, refer to Table 6.

14 The effects of mobile data use were found to be insignificant using the asinh transformation. As such, an additional variable was included within the function to accommodate variety of non-linear relationships.

B.5 Results

Table 7 reports the results of the estimation:

Table 7. Econometric results

Econometric results						
Arellano-Bond dynamic panel-data estimation				Number of obs	=	56
Group variable: countryID				Number of groups	=	14
Time variable: year						
				Obs per group:	avg =	4
Number of instruments = 48				Wald chi2(5)	=	3389.71
				Prob > chi2	=	0.0000

ln(GDPpercap)	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
L1.ln(GDPpercap)	.5052749	.0739473	6.83	0.000	.3603409	.6502089
ln(invest)	.3061106	.0310438	9.86	0.000	.2452658	.3669554
ln(labour)	-1.646051	.5443022	-3.02	0.002	-2.712863	-.5792381
asinh(θ_1·datause)	.6473152	.3599809	1.80	0.072	-.0582344	1.352865
asinh(θ_2·mobpen)	.278605	.0867689	3.21	0.001	.108541	.4486689
_cons	33.13481	9.864574	3.36	0.001	13.8006	52.46902

Source: Deloitte analysis

All coefficients are of the expected sign, except labour force, which is negative. This might be due to potential multicollinearity with the investment variable. All variables are significant at the 5% level except mobile data usage, which is significant at the 7% level.[15]

The computation of the marginal effect of mobile usage per 3G connection on the annual growth rate of GDP per capita requires transformation of the coefficient of this variable. The marginal effect of mobile data usage per 3G connection differs across countries depending on the amount of average data usage per 3G connection in each. The effect of doubling mobile data usage per 3G connection on annual GDP per capita growth rate is calculated using the formula below. For a country with average annual data consumption of X Kb per 3G connection during 2005-2010, the effect of doubling this consumption on GDP per capita growth is:

$$ME = \beta \cdot \frac{1}{\sqrt{(\theta_1 X)^2 + 1}} \theta_1 \cdot X \cdot 100$$

where β is the coefficient on the variable asinh(θ_1·datause) and θ_1 is the parameter within the transformation.

Averaging this impact across all countries in the sample, it is found that doubling mobile data use per 3G connection would lead on average to an increase in the annual GDP growth rate of 0.5 percentage points. This figure is calculated as the weighted average of the individual marginal effects for each country of the sample, where the marginal effect for each country is weighted by the number of 3G connections. This is in order to attach to each country's marginal effect a weight proportional to the size of the mobile market in the country.

15 The reported standard errors were computed based on the conventionally derived variance estimator for generalized method of moments estimation. Given the limited size of the sample available (14 countries), it appears reasonable to lower the significance threshold for the data usage coefficient to 90% in this case. Additionally, to confirm the validity of all standard errors, bootstrapped estimates of the standard errors were computed (not reported here) and all parameters of the model were found to be significant at 5% level.

B.6 Diagnostic tests

Below are the details of two post-estimation diagnostic tests supporting the choice of the instrumental variables employed in the estimation.

The first test (Table 8) shows no evidence to suggest that the instruments are correlated with the error term, thus justifying their use. This is necessary for the consistency of the estimates.

Table 8. Sargan test of over-identifying restrictions

Sargan test of over-identifying restrictions
H0: overidentifying restrictions are valid
chi2(42) = 6.073514
Prob > chi2 = 1.0000

Source: Deloitte analysis

Table 9 below presents the result of the Arellano-Bond test, which confirms that the idiosyncratic error term $\varepsilon_{i,t}$ is not serially correlated. This is a necessary assumption for ensuring the validity of the instrumental variables employed in the analysis.

Table 9. Arellano-Bond test for zero autocorrelation

Arellano-Bond test for zero autocorrelation in first-differenced errors

H0: no autocorrelation in the first-differenced errors

Order	z	Prob > z
1	-.68643	0.4924
2	-1.3764	0.1687

Source: Deloitte analysis

Appendix C: Mobile telephony and productivity in developing markets

This appendix presents the details of the econometric estimation carried out in order to assess the impact of mobile penetration on productivity in developing markets.[16]

C.1 Objectives and background

The literature[17] on the GDP impact of the uptake of mobile telephony identifies two distinct channels through which mobile telephony contributes to improving GDP growth: a direct impact and an indirect impact.

The direct impact can be captured by interpreting the level of mobile penetration in a market as a proxy for the degree of development of the mobile telecommunications industry in the country. Countries with higher levels of mobile penetration tend to be the countries with comparatively higher levels of capital investment in the mobile sector. Higher investment in the mobile sector generates more employment, more mobile-related economic activity and more activity in the wider economy. For these reasons, mobile penetration can be thought of as an input of the aggregate GDP production function, as illustrated in the equation below. This captures the effect of the so-called 'capital deepening', that is, the effect of a higher level of capital (mobile ICT capital in this case) per each individual.

$$GDP = f(Capital, Labour, Mobile\ Penetration, \dots)$$

The indirect impact that mobile penetration exerts on a country's GDP is related to fact that wider access to mobile telecommunications reduces transaction costs, promotes organisational efficiency and allows faster information flow and dissemination. This effect can be captured by studying the impact of mobile penetration on Total Factor Productivity ('TFP'). Increases in TFP lead to increases in GDP through better utilisation of capital and labour inputs, which therefore become more productive:

$$GDP = TFP \cdot f(Capital, Labour, \dots)$$
$$where \quad TFP = g(Mobile\ Penetration, \dots)$$

While the direct impact was investigated and quantified in previous studies[18], the indirect impact is the focus of this section.

C.2 The dataset employed

Table 10 shows a detailed list of the countries included in the sample.

Table 10. List of countries used in the mobile penetration and productivity analysis

Region	Countries
Africa and Middle East	Algeria; Bahrain; Botswana; Cameroon; Cape Verde; Central African Republic; Chad; Comoros; Democratic Republic of Congo; Republic of Congo; Cote d'Ivoire; Egypt; Eritrea; Ethiopia; Gambia; Ghana; Guinea; Jordan; Kuwait; Lebanon; Lesotho; Madagascar; Malawi; Mali; Mauritania; Mauritius; Morocco; Mozambique; Namibia; Oman; Rwanda; Senegal; Sudan; Swaziland; Syria; Tanzania; Tunisia; Uganda; Yemen; Zambia.
Asia Pacific	Bhutan; Brunei Darussalam; Cambodia; Fiji; India; Indonesia; Malaysia; Philippines; Sri Lanka; Tonga; Vanuatu; Vietnam.
Americas	Argentina; Bahamas; Barbados; Belize; Bolivia; Brazil; Chile; Colombia; Costa Rica; Dominican Republic; Ecuador; El Salvador; Guatemala; Mexico; Panama; Paraguay; Peru; St. Lucia; Trinidad and Tobago; Uruguay; Venezuela.

Source: Deloitte analysis

16 For a more qualitative survey of the productivity benefits of mobile telephony, see: World Bank ICT Policy Division (2008), "The role of mobile phones in sustainable rural poverty reduction".

17 Thompson and Garbacz (2007).

18 Qiang and Rossotto, with Kimura (2009); Waverman, Meschi and Fuss (2005); Deloitte (2006); Andrianaivo and Kpodar (2011); Lee, Levendis and Gutierrez (2009).

An initial dataset was constructed using publicly available data from the World Bank's World Development Indicators[19] and other publicly available sources. Only countries for which data was available for all variables and time periods of interest have been retained in the sample. This generated a panel of 74 countries measured across the period 1995-2010.

Table 11 presents the variables included in the econometric model with their relative definition and source.

Table 11. Variables used in mobile penetration and productivity analysis

Variables	Description
GDP	Real GDP (constant USD).
Labour	Total labour force.
Investment	Aggregate investment (constant USD).
Educ	Proportion of students completing the last year of primary school in a given year (proxy for human capital).
Trade/GDP	Annual trade volume as a proportion of GDP (proxy for the 'degree of openness' to international trade) from.
GovExp/GDP	Annual government consumption expenditure for goods and services as a share of GDP.
Year	Time trend capturing the technological change common to all countries over time.
MobPen	Level of mobile penetration, measured in terms of mobile phone subscribers per 100 population.
Economic Freedom Index	This is an overall index (from 1 to 100) of economic freedom. Using a scale from 0 to 100 (where 100 represents the maximum freedom) a grade is given to each country considering ten categories of economic freedom: property rights, freedom from corruption, fiscal freedom, government spending, business freedom, labour freedom, monetary freedom, trade freedom, investment freedom, and financial freedom.

Source: All variables are from the World Bank's World Development Indicators,[20] except the Economic Freedom Index, which is constructed by the Heritage Foundation.[21]

C.3 Our approach

The approach adopted captures the positive effects of mobile penetration on productivity by looking at the relationship between mobile penetration itself and the TFP. The TFP impact of an increase in mobile penetration can be studied by carrying out a Stochastic Frontier Analysis ('SFA'), which is an econometric technique specifically developed to compare productivity across a number of observations (a panel of countries, in this case).

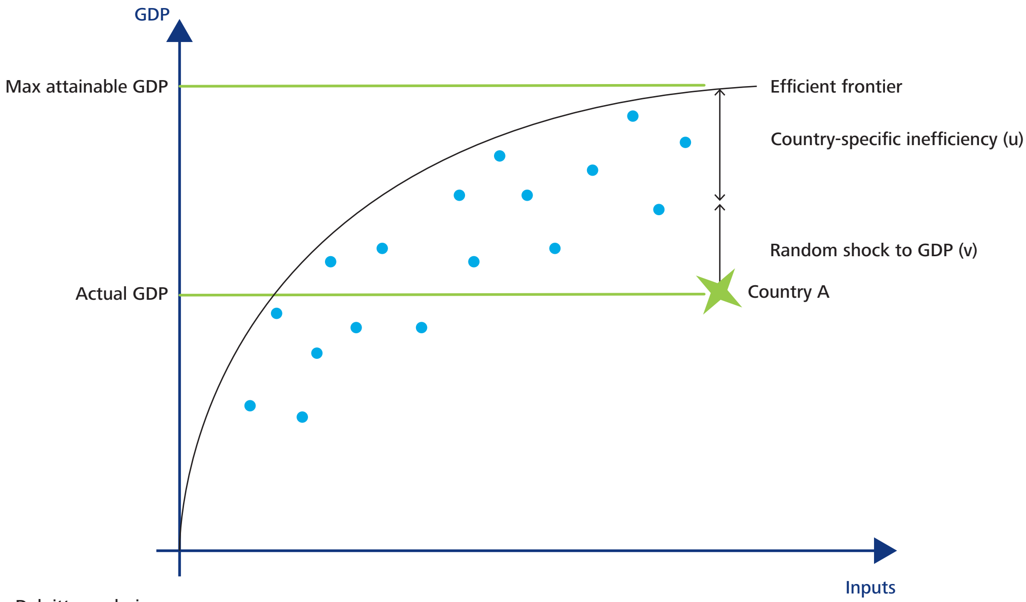
19 Available from: http://data.worldbank.org/indicator.

20 Available from: http://data.worldbank.org/indicator.

21 Available from: http://www.heritage.org/index/explore.

In a cross country GDP regression, the SFA model assumes the existence of a theoretical production possibility frontier that each country could achieve for given quantities of inputs such as labour and capital (see Figure 6). The model assumes that at most one country lies on this theoretical efficient frontier, while all other countries lie below the frontier, for two reasons: first, each country is assumed to be characterised by a certain level of country-specific inefficiency (the term 'u' in Figure 6 below), and second, a lower-than-optimal production could be due to random shocks to GDP associated with the business cycle (the term 'v' in the same figure). The SFA model allows separation of the true country specific inefficiency from the random shocks to GDP and study of the factors that can improve it. This model allowed testing of whether countries with higher levels of mobile penetration are associated with lower levels of inefficiency, i.e. higher productivity.

Figure 6. The stochastic frontier model



Source: Deloitte analysis

Figure 6 shows how each country (represented by a dot) lies below the frontier of maximum productivity. Considering country A, the difference between its maximum theoretically attainable GDP production and its (lower) actual GDP is mainly due to two separated elements: country A's inefficiency term (u) and a random shock term due, for instance, to the business cycle in the country (v). While country A has no control over the random shocks (v) to its GDP, it could potentially increase its productivity by improving mobile penetration and reduce inefficiency u. For instance, over the years, availability of mobile telephony services such as SMS and Mobile to Mobile ('M2M') have improved productivity and social inclusion in sectors such as agriculture, education, finance and health.

C.4 The model

TFP enters the GDP production function as a multiplicative term, therefore enhancing the GDP output resulting from any given quantity of inputs such as labour and capital. Mobile penetration contributes to increasing TFP, as shown in the equation:

$$GDP_{i,t} = f(X_{i,t}) \cdot TFP_{i,t} \cdot e^{v_{i,t}}$$

$$\text{where} \quad X_{i,t} \text{ includes: } Capital_{i,t}, Labour_{i,t}, Educ_{i,t}, \frac{Trade}{GDP}_{i,t}, \frac{GovExp}{GDP}_{i,t}, Year$$

$$f(X_{i,t}) \text{ is Cobb-Douglas, and}$$

$$TFP_{i,t} = e^{\alpha - \mathrm{u}_{\mathrm{i,t}}}$$

equation 5

This represents an SFA model where the term $u_{i,t}$ measures the productive inefficiency, is described by the following distribution: and can be modelled as follows:

$$\ln(u_{i,t}) = \delta - \gamma_1 \operatorname{asinh}(MobPen_{i,t}) - \gamma_2\, EconFreedomIndex_{i,t} + w_{i,t}$$

$$\text{where} \quad w_{i,t} \sim iidN(0, \sigma_w^2)$$

equation 6

In equation 5, α represents a constant term, u is a (negative) country specific inefficiency term and v is the usual idiosyncratic error term. Equation 6 describes how the country specific inefficiency term can be reduced by improving a country's mobile penetration. In this representation, therefore, mobile penetration effectively contributes to improving TFP.[22]

From the estimation of equation 5, one can extract inefficiency term u for each country and subsequently regress it against mobile penetration to test if higher mobile penetration contributes to improving TFP.[23]

22 Mobile penetration is transformed according to the inverse hyperbolic sine function (asinh) which is needed in order to account for observations characterised by zero mobile penetration in early years. A simple logarithmic transformation would not allow for this.

23 As pointed out in Thompson and Garbacz (2007), SFA models do not allow to readily address potential endogeneity of the regressors using conventional methods. However, it is expected that mobile penetration will not be endogenous with respect to TFP.

C.5 Results

Table 12 reports the results of the two stages of the estimation.

Table 12. Econometric results

Econometric results

First stage:
GDP stochastic frontier regression

Number of obs	= 1110
Number of groups	= 74
Obs per group: avg	= 15
Wald chi2(6)	= 6916.12
Prob > chi2	= 0.0000

Log likelihood = 997.50468

ln(gdp)	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
ln(labour)	.4411701	.0438724	10.06	0.000	.3551818	.5271583
ln(invest)	.1395836	.0092631	15.07	0.000	.1214282	.157739
ln(educ)	.1208798	.017158	7.05	0.000	.0872507	.1545089
year	.0197479	.0012978	15.22	0.000	.0172044	.0222915
ln(trade/gdp)	0342232	.0154556	2.21	0.027	.0039307	.0645156
ln(gov/gdp)	0220467	.0132115	1.67	0.095	-.0038473	.0479406

Second stage:
Inefficiency regression

Number of obs	= 990
F(2, 987)	= 40.12
Prob > F	= 0.0000

ln(u)	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
asinh(mobpen)	-.0866869	.0140609	-6.17	0.000	-.1142795	-.0590942
econ_freedom	-.0122314	.0030118	-4.06	0.000	-.0181417	-.0063211
cons	1.500023	.1698889	8.83	0.000	1.166638	1.833408

Source: Deloitte analysis

Coefficients for all variables in the GDP stochastic frontier regression present the expected sign and only one (government expenditure) is not significant. Both coefficients in the inefficiency regression are of the expected sign (negative, i.e. both variables contribute to reducing a country's inefficiency).[24]

Mobile penetration, transformed using the inverse hyperbolic sine (asinh) function, is allowed to have a non-linear effect on TFP. As such, the impact of a 10% increase in mobile penetration will depend on the average level of mobile penetration in the country.

In order to calculate the effect on TFP of a 10% increase in mobile penetration for a given country, the following transformation has to be applied to the coefficient (γ_1) of the mobile penetration variable, *asinh(MobPen)*:

$$\frac{d\,u}{d\,\mathrm{MobPen}} = 1000\frac{\gamma_1}{\sqrt{\mathrm{MobPen}^2 + 1}}$$

where the above function is evaluated at the average mobile penetration from 1995 to 2010 for the country.

For instance, given an average penetration of X% during 1995-2010, the effect on TFP is:

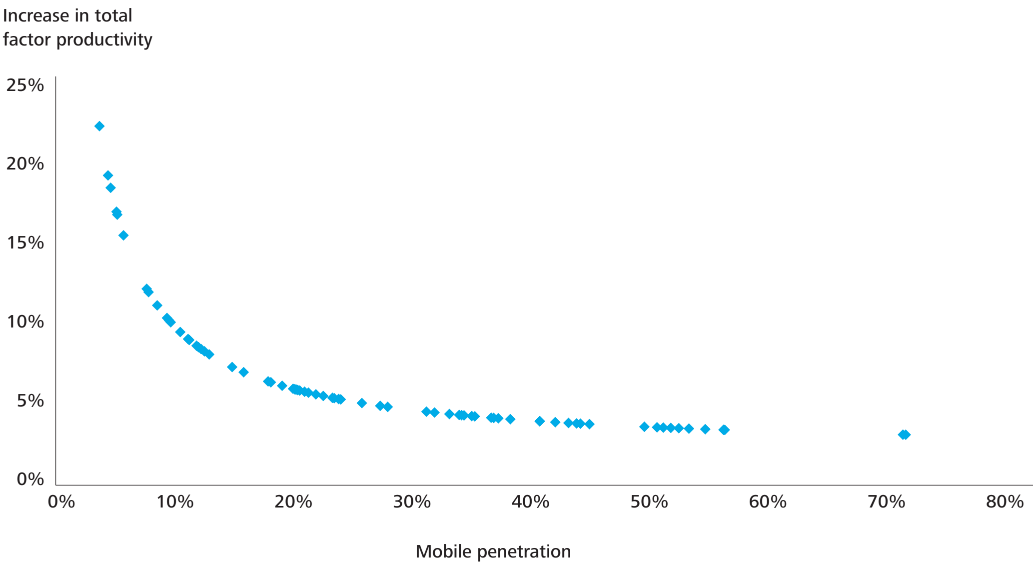
$$\frac{d\,u}{d\,\mathrm{MobPen}} = 1000\frac{\gamma_1}{\sqrt{\mathrm{MobPen}^2 + 1}} = 1000\,\frac{0.0866869}{\sqrt{X^2 + 1}}$$

24 Tests for unit root tests do not reject the null hypothesis of stationarity in the covariates. GDP was found to be I(1); however, this will not affect consistency of the MLE in this case.

The interpretation is that for a country with X% average penetration during 1995-2010, a 10% increase in mobile penetration would raise TFP by $1000\frac{0.0866869}{\sqrt{X^2+1}}$ percentage points in the long run.

Figure 7 shows by how much TFP would increase if mobile penetration increased by 10% for different levels of mobile penetration. The analysis shows that the marginal effect of mobile phone penetration on TFP varies across countries with the average level of mobile penetration. Mobile penetration has a higher impact on TFP in countries with low levels of penetration than on countries with higher levels of penetration.

Figure 7. Effect of a 10% increase in mobile penetration on productivity in each country[25]



Source: Deloitte analysis

Overall, across the whole sample of countries considered, if countries had a 10% higher mobile penetration between 1995 and 2010, they would have experienced a TFP increase of 4.2 percentage points in the long run. This figure is calculated as the weighted average of the individual marginal effects for each country, where the marginal effect for each country is weighted by the number of mobile subscribers, in order to attach to each country's marginal effect a weight proportional to the size of the mobile market in the country.

25 This figure excludes two countries with average penetration below 2% during the period 1995 to 2010.

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