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The economic contribution of broadband, digitization and ICT regulation: Econometric modelling for the ITU Europe region

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Foreword

The transformative power of digital technologies and connectivity is empowering people, creating an environment that nurtures innovation, and is triggering positive change in business processes and in the global economy.

The recent ITU global study on the economic contribution of broadband, digitization and information and communication technology (ICT) regulation provided a global econometric analysis of robust and reliable data resources to measure the impact of fixed and mobile broadband and digital transformation on the economy as a whole. It also analysed the impact of institutional and regulatory variables to the development of the digital ecosystem.

Based on the data and analysis to measure the impact of digitization as a whole, a further need was identified to conduct studies that delved deeper into these effects, focusing on specific regions of the world. By applying the same methodologies and econometric models used for assessing global effects, this report focuses on the impact of broadband, digital transformation and policy and regulatory frameworks on the growth of markets for digital services in the Europe region.

This report also provides evidence of the importance of regulatory and institutional variables in driving digital growth, illustrating that broadband technologies and effective ICT regulation can have a positive impact on the growth of national economies and prosperity.

This ITU report suggests that an increase of 10 per cent in mobile broadband penetration in the Europe region would yield an increase in 2.1 per cent in GDP per capita. The report validated the positive impact of the policy and regulatory component in the region as well, suggesting that an increase of 10 per cent in the ITU ICT Regulatory Tracker yields a positive increase in the CAF Digital Ecosystem Development Index of 0.61 per cent in the region.

I am delighted to present this ever-growing research for the Europe region as a guidance to assist membership in designing smart and sustainable policies and strategies to reap the benefits of the dynamic and exciting broadband ecosystem.

Doreen Bogdan-Martin
Director, ITU Telecommunication Development Bureau

Table of Contents

List of Tables and Figures

Tables

Figures

1 Introduction

The *Economic contribution of broadband, digitization and ICT regulation: econometric modelling for the ITU Europe region* provides a set of econometric analyses that estimate the economic contribution of broadband and digitization, as well as the impact of ICT policy on the development of the digital economy. A summary of the econometric methodology applied is presented in annex C. This report provides substantial evidence regarding the impact of broadband and digital transformation on the economy as well as the impact of institutional and regulatory variables on the growth of the digital ecosystem.

This report follows the findings of the ITU global study, published in 2018, on the economic contribution of broadband, digitization, and ICT regulation[1], which was based on a large set of sample economies, and demonstrated the following impacts and effects:

- Fixed broadband economic impact is guided by a returns to scale effect[2], according to which the economic impact of fixed broadband is greater in high-income country economies than in low-income country economies.
- The economic impact of mobile broadband reflects a saturation effect, according to which the mobile broadband contribution to the economy is higher in low-income country economies than in mid- and high-income country economies.
- The impact of the digital ecosystem on countries with developed country economies is higher than in developing country economies.
- The regulatory and policy framework has a consistent impact on the development of the digital ecosystem, regardless of the level of development or income.

This evidence was considered significant for policy makers and regulators, in particular with regards to two key issues:

1. Which technologies should become a policy priority in terms of adoption?
2. How to ensure that, beyond broadband adoption, policies are deployed to stimulate the development of the digital ecosystem?

The conclusions generated by this research have prompted calls to conduct studies that delve deeper into these effects, focusing on specific regions of the world. By applying the same methodologies and models used for assessing global effects, the present report focuses on the 46 countries making up the ITU Europe region. It is complemented by studies assessing these effects in other regions of the world[3]. Section 2 of this report summarizes the results of the ITU 2018 global study, while section 3 presents the results of the analyses for the ITU Europe region.

[1] The economic contribution of broadband, digitization and ICT regulation. https://www.itu.int/en/ITU-D/Regulatory-Market/Documents/FINAL_1d_18-00513_Broadband-and-Digital-Transformation-E.pdf

[2] Generally, the returns to scale effect refers to a reduction in unit cost as the scale of production increases over time, when inputs such as physical capital usage are variable. The ITU report on the impact of broadband on the economy, 2012 (https://www.itu.int/ITU-D/treg/broadband/ITU-BB-Reports_Impact-of-Broadband-on-the-Economy.pdf) states that according to the returns to scale theory, the economic impact of broadband increases exponentially with the penetration of the technology.

[3] Regional Studies on the Economic contribution of broadband, digitization and ICT: Econometric modelling for Africa, the Americas, Arab States, Asia-Pacific and Europe. See https://www.itu.int/pub/D-PREF-EF/en.

2 The effects identified on a global scale

This section presents the types of analyses and methodologies and the results presented in the ITU 2018 global study (see footnote 1).

The ITU global study focused on testing three effects:

1. The economic contribution of fixed and mobile broadband.
2. The economic contribution of digitization (a variable that subsumes broadband technology within a larger set of digital ecosystem components)[4].
3. The impact of the policy and regulatory frameworks on the growth of markets for digital services and applications.

The findings for each of the analyses is presented in the following section in order to provide the context within which the models for the countries in the ITU Europe region are specified.

2.1 Economic impact of fixed broadband

The structural econometric model[5], composed of four equations[6], generated evidence of the impact of fixed broadband on the economy between 2010 and 2017. The results, based on a model run for a 139 country sample (general fixed broadband model), showed that an increase of 10 per cent in fixed broadband penetration yielded an increase in 0.8 per cent in gross domestic product (GDP) per capita.

The sample was split into three sets (high-, medium-, and low-income countries) to test whether the fixed broadband contribution to GDP increased or decreased depending on the level of economic development:

1. Countries with GDP per capita higher than USD 22 000 (50 countries)
2. Countries with GDP per capita between USD 12 000 and USD 22 000 (26 countries).
3. Countries with GDP per capita lower than USD 12 000 (63 countries).

The results supported the hypothesis that the economic contribution of fixed broadband increases with economic development:

- high-income countries: a 10 per cent increase in fixed broadband penetration yields 1.4 per cent increase in GDP growth;
- middle-income countries: a 10 per cent increase in fixed broadband penetration yields 0.5 per cent increase in GDP growth;
- low-income countries: while the coefficient of fixed broadband was similar to that of middle-income countries (10 per cent increase in fixed broadband penetration yields 0.5 per cent increase in GDP growth), the impact was not statistically significant[7].

2.2 Economic impact of mobile broadband

The ITU 2018 global study also showed that mobile broadband has a higher impact than fixed broadband on the world economy. Relying on a structural model run for a 139 country sample (general mobile broadband model), it was estimated that on average an increase of 10 per cent in mobile

4 Digitization development is measured by the CAF Index of Development of Digital Eco-system (see indicators that are part of this index in Appendix B) and calculation method in Katz and Callorda, 2018.

5 Structural models are defined as models build upon a set of simultaneous equations used when phenomena are assumed to be reciprocally causal (for example, is broadband contributing to the economy or is economic development driving the growth of broadband?) and the purpose is to measure one of the directions of causality (e.g. broadband contributes to the economy).

6 Detailed description of models and methodologies can be found in the ITU global study cited in footnote 1.

7 The coefficient is not statistically significant due to the lack of proof of causality in that model.

broadband penetration yielded an increase of 1.5 per cent in GDP. However, using the same three data sets (high-, medium-, and low-income countries) to test the economic impact of mobile broadband showed that the level of economic contribution of mobile broadband is higher in low-income countries than in high-income countries, where it had no impact:

- high-income countries: no economic impact was detected;
- middle-income countries: an increase of 10 per cent in mobile broadband penetration yielded an increase in 1.8 per cent in GDP;
- low-income countries: an increase of 10 per cent in mobile broadband penetration yielded an increase of 2 per cent in GDP.

This difference reflects the high levels of access to fixed broadband in high-income countries, while mobile network access to broadband is the only technology available to the majority of consumers in low-income countries. Consequently, the mobile broadband contribution to high-income economies is only marginal and the impact of mobile broadband in low-income countries is extremely important.

2.3 Economic impact of digitization

The ITU 2018 global study tested the economic impact of digitization using an endogenous growth model that linked GDP to the fixed stock of capital, labour force, and the CAF Digital Ecosystem Development Index (see section 3.5). The approach followed in this case tested the economic contribution for a sample of 73 countries worldwide (the general digitization model) and then split the results into two sets of countries: those within the Organization for Economic Co-operation and Development (OECD)[8] and non-OECD countries. According to the general digitization model, an increase of 10 per cent in the CAF Digital Ecosystem Development Index yielded a 1.3 per cent growth in GDP per capita. When the sample was split between OECD and non-OECD countries[9], economic impact was greater in OECD countries relative to non-OECD countries:

- OECD countries: An increase of 10 per cent in the CAF Digital Ecosystem Development Index yielded a 1.4 per cent growth in GDP per capita.
- Non-OECD countries: An increase of 10 per cent in the CAF Digital Ecosystem Development Index yielded a 1.0 per cent growth in GDP per capita.

Furthermore, a single variable model with country and period fixed effects indicated that digitization also has an impact on labour and total factor productivity. An increase in the digitization index of 10 per cent yielded an increase in labour productivity of 2.6 per cent and in total factor productivity of 2.3 per cent.

2.4 Impact of policy and regulatory framework on digitization development

In the ITU 2018 global study, the contribution to digitization development was tested through a multivariate regression model with fixed effects based on two independent variables: the ITU ICT Regulatory Tracker[10] and a year lag of the same variable for control purposes[11]. The model provided

[8] Australia, Austria, Belgium, Canada, Chile, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Republic of Korea, Latvia, Lithuania, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom, United States of America.

[9] This distinction is made to attempt to determine whether in advanced economies digitization has a higher economic contribution than in emerging countries. Most OECD nations are industrialized although a few emerging countries that abide to its regulatory and policy principles are also members.

[10] ITU ICT Regulatory Tracker is available at https://www.itu.int/net4/itu-d/irt/#/tracker-by-country/regulatory-tracker/2017

[11] The year lag is the same variable (the ICT Regulatory Tracker Index) but included for a year before (t-1); this is done to isolate the effect of regulation in past years.

further evidence of the importance of the regulatory and institutional variable in driving digital ecosystem growth. An increase of 10 per cent in the ITU ICT Regulatory Tracker yielded a positive increase in the CAF Ecosystem Development Index of 0.348 per cent in the subsequent time period.

Having presented the analyses, methodologies and results relied upon for the ITU global study, section 3 below focuses on validating the results with the regional studies focusing on countries of the ITU Europe region, starting with a review of the research literature on economic contribution of broadband in the region.

3 The economic contribution of broadband and digitization and the impact of policy on digitization in the Europe region

This section analyses broadband and digitization economic contribution for the ITU Europe region. The countries included in this analysis are Albania, Austria, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Georgia, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Latvia, Lithuania, Luxembourg, North Macedonia, Moldova, Montenegro, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom[12].

3.1 Review of the research literature

Research on the economic impact of broadband in the Europe region has produced many studies over the past two decades. The output is clustered around three theoretical and methodological bodies:

- Input-output analysis.
- Econometric modelling.
- Micro-economic and experimental research.

A number of input-output analyses focused primarily on measuring the impact of investment in broadband infrastructure as a trigger of significant and positive impact on the economy, as measured through GDP and job creation. Katz et al. (2008) developed one of the first pieces of work focused on Europe by estimating the impact on output and jobs of a CHF 13.2 billion investment on a nationwide optical fibre network in Switzerland. It is estimated that deployment of such a network could result in value added equivalent to CHF 9.843 and generate 114 000 jobs, broken down to 83 000 direct jobs and 31 000 indirect jobs. In a similar approach, Liebenau et al. (2009) estimated through input-output analysis, the impact on GDP and employment of an investment of USD 7.5 billion needed to achieve the target of the *Digital Britain* plan. In another example, Katz et al. (2010) estimated the impact on the GDP and employment of the investment attached to the implementation of Germany's National Broadband Strategy announced in 2009. Triggered by a total estimated investment of Euros 35.93 billion, this private and public effort would result in a total GDP contribution (which includes the amount invested) of Euros 93.07. In another study relying on input-output analysis, Analysys Mason (2013) estimated the impact on GDP of the implementation of the European Union Digital Agenda.

Econometric analysis has been implemented either on a cross-sectional sample or focused on specific countries. Some cross-sectional studies have focused on OECD countries. For example, a study undertaken by Czernich *et al*. in 2009 investigated broadband economic impact in 25 OECD countries between 1996 and 2005. The research found that a 10 per cent increase in broadband penetration results in an increase in GDP growth of between 0.9 per cent and 1.5 per cent. Relying on a structural model similar to the one used in the global study cited above, Koutroumpis (2009) published a study of

[12] Six countries excluded because lack of data: Andorra, Liechtenstein, Malta, Monaco, San Marino, and Vatican.

22 OECD countries between 2002 and 2007, which found that an increase in broadband penetration of 10 per cent yields a 0.25 per cent increase in economic growth, and confirmed the effect in a similar study in 2018, albeit with a larger data set. Focusing on the countries of the European Union, Gruber et al. (2014) applied an econometric model to estimate the economic benefits derived from the implementation of broadband deployment targets stipulated by the EU Digital Agenda.

As an example of studies at the national level, Katz et al. (2010) built econometric models for the underdeveloped and advanced areas of broadband in Germany based on time series between 2000 and 2006. In one of the first studies that highlighted the returns to scale effect at the country level, the regression models estimated that an increase of 10 per cent in broadband penetration yielded a growth in GDP equivalent to 0.26 per cent in areas with high levels of broadband penetration and 0.24 per cent in underdeveloped areas.

Microeconomic research has also been utilized to estimate the impact of broadband on job creation and productivity. Bertschek, Cerqueray and Kleinz (2011) used the results of regular surveys of 4 400 firms, analysing the early phase of DSL expansion in Germany from 2001 to 2003, when roughly 60 per cent of German firms already used broadband Internet. While the study found that the broadband labour productivity impact is highly heterogeneous among firms and not statistically different from zero, the impact of broadband on the innovation activity of firms was positive. In their research focused on the countries of the European Union, Fornefeld *et al.*, (2008) examined two case study areas (Cornwall, United Kingdom, and Piemonte, Italy) and collected and compared company survey and regional macro-economic data prior to broadband deployment and after deployment. The research found that companies adopting broadband-based processes improved labour productivity by 5 per cent in the manufacturing sector, and by 10 per cent in the services sector. These results, as well as other research on the impact of ICTs and broadband on job creation, suggest three ways that broadband impacts employment:

- The introduction of new applications and services causes acceleration of innovation.
- The adoption of more efficient business processes enabled by broadband increases productivity.
- The ability to process information and provide services remotely makes it possible to attract employment from other regions through outsourcing.

These elements impact employment simultaneously: the *productivity effect* and potential loss of jobs due to outsourcing are neutralized by the *innovation effect*. The evidence suggests that a negative effect on productivity is compensated by an increase in the rate of innovation and services, resulting in the creation of new jobs elsewhere.

In sum, all three bodies of research confirm, with varying levels of impact, a significant contribution of broadband to the economy in the Europe region.

3.2 Hypotheses

The group of countries considered in the Europe region includes nations with different levels of economic development, heterogeneous socio-economic contexts and market dynamics[13]. Based on

[13] For example, countries with a GDP per capita higher than USD 20 000 include Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Iceland, Ireland, Israel, Italy, Netherlands, Norway, Poland, Portugal, Slovenia, Spain, Sweden, Switzerland, and the United Kingdom. On the other hand, the countries under the USD 20 000 per capita threshold include Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Georgia, Hungary, Latvia, Lithuania, North Macedonia, Moldova, Romania, Serbia, Slovak Republic, Turkey and Ukraine.

this, and considering the evidence generated in the ITU Global Study that preceded this analysis, the following hypotheses are stipulated:

- Economic impact of fixed broadband: while the *aggregate* for the Europe region is expected to fall between low- and high-income countries in the global sample, the contribution among high-income countries in the Europe region is substantially higher.
- Economic impact of mobile broadband: this should also fall between low- and high-income countries for the Europe region in the global sample. However, in this case the impact is higher among low-income countries for the Europe region.
- Impact of digitization: a similar effect would be expected in the case of digitization, where the contribution of digitization to the economy should be closer to the levels estimated for OECD countries.

3.3 Economic impact of fixed broadband in Europe

The estimation of the economic contribution of fixed broadband in Europe relied on the same structural model used in the ITU 2018 global study and in the estimation of effects in the other regions. The model consists of four equations: an aggregate production function modelling the economy and, subsequently, three functions: demand, supply and output. However, in order to test the hypothesis regarding high- and low-income countries in the Europe region, the model was run for the aggregate sample as well as for the two country groupings mentioned in section 3.2 (see footnote 12).

Data

To test the hypothesis of fixed broadband economic impact presented above, a database of the countries was built, containing time series for all the required variables between 2007 and 2018[14]. The data sources are: International Telecommunication Union, the World Bank, and Ovum (see annex A for data sources)[15].

Model results and discussion

As mentioned above, the structural model was first run for the complete sample of countries in the Europe region. The results are presented in Table 1.

Table 1: Economic impact of fixed broadband in the ITU Europe region (2007-2018)

GDP per capita	
Fixed broadband subscriber penetration	0.04628 ***
Capital	0.43478 ***
Education	-0.14438
Fixed broadband subscriber penetration	
Fixed telephone subscribers	0.20777 ***
Rural population	-0.04282 ***
GDP per capita	0.40266 ***

14 The publication of the ITU World Telecommunications/ICT Indicators Database 2019 (June edition), released on July 26, 2019 allowed the inclusion of another year in the data panels of this study; this was not the case for the global study cited above.

15 Countries excluded from the fixed broadband model because of lack of data regarding market composition, which enables the calculation of the Herfindahl-Hirschman Index of market concentration: Montenegro and Luxembourg.

Fixed broadband price	-0.20826 ***
HHI**** fixed broadband	-0.08293 ***
Revenue fixed broadband	
GDP per capita	1.11701 ***
Fixed broadband price	-0.04014
HHI fixed broadband	-0.44716 ***
Fixed broadband adoption growth	
Revenue fixed broadband	-1.07670 ***
Observations	1,710
Number of countries	38
Country fixed effects	Yes
Year and quarter fixed effects	Yes
Years	2007-2018
R-Squared first model	0.9936

***, **, * significant at 1%, 5%, and 10% critical value respectively.

****HHI (Herfindahl-Hirschman Index)

As expected, fixed broadband has made a moderate economic contribution in countries in the Europe region from 2007 to 2018, where an increase of 10 per cent in fixed broadband penetration has yielded an increase in 0.46 per cent in GDP per capita.

In addition, while capital formation presents the appropriate sign and order of magnitude for a production function, labour does not depict any effect because the indicator used to measure its contribution- tertiary school enrolment- has no variance in the period under analysis.

In order to test for the heterogeneity of the sample of countries in the Europe region, the model was run for two subsets of countries: countries with a GDP per capita higher than USD 20 000 and countries under the USD 20 000 per capita threshold. The results confirm the hypotheses regarding fixed broadband (see Table 2).

Table 2: Economic impact of fixed broadband (2007-2018) (high-income and low-income countries)

GDP per capita	All countries	Low-income [16]	High-income [17]
Fixed broadband subscriber penetration	0.04628 ***	0.00731	0.29365 ***
Capital	0.43478 ***	0.31868 ***	0.60027 ***
Education	-0.14438	-0.24854 *	-0.77101 ***

[16] Countries with GDP per capita lower than USD 20 000: Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Georgia, Hungary, Latvia, Lithuania, North Macedonia, Moldova, Romania, Serbia, Slovakia, Turkey, Ukraine

[17] Countries with GDP per capita higher than USD 20 000: Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Iceland, Ireland, Israel, Italy, Netherlands, Norway, Poland, Portugal, Slovenia, Spain, Sweden, Switzerland, United Kingdom.

GDP per capita	All countries	Low-income [16]	High-income [17]
Fixed broadband subscriber penetration			
Fixed telephone subscriber	0.20777 ***	0.47456 ***	0.12679 ***
Rural population	-0.04282 ***	-0.00577	-0.05502 ***
GDP per capita	0.40266 ***	0.59545 ***	0.11453 ***
Fixed broadband price	-0.20826 ***	-0.38451***	-0.04187 **
HHI fixed broadband	-0.08293 ***	-0.09277 ***	-0.00575
Revenue fixed broadband			
GDP per capita	1.11701 ***	1.18153 ***	0.77166 ***
Fixed broadband price	-0.04014	-0.27746***	0.37078 **
HHI fixed broadband	-0.44716 ***	0.07631	-1.17299 ***
Fixed broadband adoption growth			
Revenue fixed broadband	-1.07670 ***	-2.22891 ***	-0.15913 ***
Observations	1,710	720	990
Number of countries	38	16	22
Country fixed effects	Yes	Yes	Yes
Year and quarter fixed effects	Yes	Yes	Yes
Years	2007-2018	2007-2018	2007-2018
R-Squared first model	0.9936	0.9849	0.9724

***, **, * significant at 1%, 5%, and 10% critical value respectively.

According to the results shown in Table 2, the contribution of fixed broadband to GDP in high income countries in the Europe region increases to 2.94 per cent for an increase of 10 per cent in fixed broadband penetration. Conversely, the contribution of fixed broadband to GDP in low-income countries is not statistically significant (therefore, equal to zero).

The results for the split samples of countries in the Europe region are aligned with the global model (see Table 3).

Table 3: Economic impact of fixed broadband (high- and low-income countries compared to ITU global study high- and low-income countries)

	Low-income countries		High-income countries	
	ITU global study	Europe	ITU global study	Europe
GDP per capita				
Fixed broadband subscriber penetration	0.05461	0.00731	0.14047 ***	0.29365 ***
Capital	0.21024 ***	0.31868 ***	0.30257 ***	0.60027 ***

	Low-income countries		High-income countries	
	ITU global study	Europe	ITU global study	Europe
Education	0.15569 ***	-0.24854 *	-0.11711 ***	-0.77101 ***
Fixed broadband subscriber penetration				
Fixed telephone subscriber	0.49262 ***	0.47456 ***	0.39270 ***	0.12679 ***
Rural population	-0.81927 ***	-0.00577	0.04370 ***	-0.05502 ***
GDP per capita	0.53821 ***	0.59545 ***	0.15746 ***	0.11453 ***
Fixed broadband price	-0.30159 ***	-0.38451***	0.22080 ***	-0.04187 **
HHI fixed broadband	-0.38882 ***	-0.09277 ***	-0.21266 ***	-0.00575
Fixed broadband revenue				
GDP per capita	1.24272***	1.18153 ***	-0.48618 ***	0.77166 ***
Fixed broadband price	0.14314 ***	-0.27746***	1.46762 ***	0.37078 **
HHI fixed broadband	-0.71760 ***	0.07631	-0.81781 ***	-1.17299 ***
Fixed broadband adoption growth				
Fixed broadband revenue	-0.74656 ***	-2.22891 ***	-0.82810 ***	-0.15913 ***
Observations	1,724	720	1,364	990
Number of countries	63	16	50	22
Country fixed effects	Yes	Yes	Yes	Yes
Year and quarter fixed effects	Yes	Yes	Yes	Yes
Years	2010-2017	2007-2018	2010-2017	2007-2018
R-Squared first model	0.9831	0.9849	0.9848	0.9724

***, **, * significant at 1%, 5% and 10% critical value respectively.

3.4 Economic impact of mobile broadband

The structural model used to test the economic contribution of mobile broadband is based on four equations: an aggregate production function modelling the economy and, subsequently, three functions: demand, supply, and output.

Data

To test the mobile broadband economic impact hypothesis presented in section 3.2 above, a database was built for Albania, Austria, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Georgia, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Latvia, Lithuania, Luxembourg, North Macedonia, Moldova, Montenegro, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom between 2011 and 2018 (in this case, Montenegro, and Luxembourg were included). The data sources are the International Telecommunication Union, the World Bank, and GSMA (see annex A for data sources).

Model results and discussion

The model, run for 40 Europe region countries, yields statistically significant results, confirming the effects identified in the ITU 2018 global study model (see Table 4).

Table 4: Economic impact of mobile broadband (2011-2018)

GDP per capita	
Mobile broadband unique subscriber penetration	0.21021 ***
Capital	0.37215 ***
Education	-0.02792
Mobile broadband unique subscriber penetration	
Mobile unique subscriber penetration	1.11568 ***
Rural population	0.02942 ***
GDP per capita	0.08279 ***
Mobile broadband price	0.00875
HHI mobile broadband	-0.25360 ***
Revenue mobile broadband	
GDP per capita	0.89812 ***
Mobile broadband price	-0.10784
HHI mobile broadband	-2.59929 ***
Mobile broadband adoption growth	
Revenue mobile broadband	-0.13631***
Observations	1,277
Number of countries	40
Country fixed effects	Yes
Year and quarter fixed effects	Yes
Years	2011-2018
R-Squared first model	0.9951

***, **, * significant at 1%, 5% and 10% critical value respectively.

According to the mobile broadband model in Table 4, an increase of 10 per cent in mobile broadband penetration yields an increase in 2.1 per cent in GDP per capita, which implies that this technology has had a significant economic impact in the Europe region over the last seven years (2011-2018).

As in the case of fixed broadband, the model was run for two subsets, divided by the level of GDP per capita: countries with a GDP per capita higher than USD 20 000, and countries under the USD 20 000 per capita threshold. The results confirm the hypothesis regarding mobile broadband (see Table 5).

Table 5: Economic impact of mobile broadband (high-income compared to low-income countries)

	All countries	Low-income[18]	High-income[19]
GDP per capita			
Mobile broadband unique subscriber penetration	0.21021 ***	0.19980 ***	-0.02055
Capital	0.37215 ***	0.24406 ***	0.47053 ***
Education	-0.02792	-0.10296	-0.44763 ***
Mobile broadband unique subscriber penetration			
Mobile unique subscriber penetration	1.11568 ***	1.11800 ***	1.03614 ***
Rural population	0.02942 ***	0.19653 ***	0.01430 **
GDP per capita	0.08279 ***	0.11953 ***	0.11343 ***
Mobile broadband price	0.00875	0.01418	-0.10805 ***
HHI mobile broadband	-0.25360 ***	-0.36759 ***	-0.13299 ***
Revenue mobile broadband			
GDP per capita	0.89812 ***	1.13292 ***	0.38652 **
Mobile broadband price	-0.10784	-0.27413 **	0.00057
HHI mobile broadband	-2.59929 ***	-2.25759 ***	-2.62058 ***
Mobile broadband adoption growth			
Revenue mobile broadband	-0.13631***	-0.22200 ***	-0.04558 **
Observations	1,277	541	803
Number of countries	40	17	23
Country fixed effects	Yes	Yes	Yes
Year and quarter fixed effects	Yes	Yes	Yes
Years	2011-2018	2011-2018	2010-2018
R-Squared first model	0.9951	0.9860	0.9792

***, **, * significant at 1%, 5%, and 10% critical value respectively.

[18] Countries with GDP per capita lower than USD 20 000: Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Georgia, Hungary, Latvia, Lithuania, North Macedonia, Moldova, Montenegro, Romania, Serbia, Slovakia, Turkey, Ukraine.

[19] Countries with GDP per capita higher than USD 20 000: Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Iceland, Ireland, Israel, Italy, Luxembourg, Netherlands, Norway, Poland, Portugal, Slovenia, Spain, Sweden, Switzerland, United Kingdom.

In a reversal of results for fixed broadband, low-income European countries depict a statistically significant high impact of mobile broadband (2% increase of GDP for every 10% increase in penetration), while the contribution of the technology in low-income countries in the Europe region cannot be detected. Again, these results are aligned with those produced in the global study (see Table 6).

Table 6: Economic impact of mobile broadband (High- and low-income countries compared to the ITU global study)

	Low-income countries		High-income countries	
	Global study	Europe	Global study	Europe
GDP per capita				
Mobile broadband unique subscriber penetration	0.19752 ***	0.19980 ***	-0.021986	-0.02055
Capital	0.23190 ***	0.24406 ***	0.31248 ***	0.47053 ***
Education	0.12406 ***	-0.10296	-0.07062 ***	-0.44763 ***
Mobile broadband unique subscriber penetration				
Mobile unique subscriber penetration	1.63963 ***	1.11800 ***	1.85883 ***	1.03614 ***
Rural population	-0.08433 ***	0.19653 ***	-0.03806 ***	0.01430 **
GDP per capita	0.04384 **	0.11953 ***	0.26726 ***	0.11343 ***
Mobile broadband price	-0.13139 ***	0.01418	0.00810	-0.10805 ***
HHI mobile broadband	-0.27510 ***	-0.36759 ***	-0.43987 ***	-0.13299 ***
Revenue mobile broadband				
GDP per capita	0.97739 ***	1.13292 ***	0.86928 ***	0.38652 **
Mobile broadband price	-0.47023 ***	-0.27413 **	0.78115 ***	0.00057
HHI mobile broadband	-1.65927 ***	-2.25759 ***	-2.70536 ***	-2.62058 ***
Mobile broadband adoption growth				
Revenue mobile broadband	-1.11108 ***	-0.22200 ***	-0.32202 ***	-0.04558 **
Observations	1,689	541	1,394	803
Number of countries	63	17	50	23
Country fixed effects	Yes	Yes	Yes	Yes
Year and quarter fixed effects	Yes	Yes	Yes	Yes
Years	2010-2017	2011-2018	2010-2017	2010-2018
R-Squared first model	0.9799	0.9860	0.9867	0.9792

***, **, * significant at 1%, 5%, and 10% critical value respectively.

The fixed and mobile broadband model results indicate that the Europe region countries, as anticipated in the hypotheses, fall between high-income and low-income countries. However, when controlling for the heterogeneity of the sample in both models, the results are in line with those of the global model, indicating high GDP contribution for fixed broadband in high-income states (returns to scale effect), and high GDP contribution for mobile broadband in low-income states (saturation effect).

3.5 Economic impact of digitization in the Europe region

The economic contribution of digitization in Europe was tested relying on the CAF Digital Eco-system Development Index. This Index can be applied to measure all countries around the world in terms of the development of their digital economy. Along the lines of what was discussed in section 3.3, the returns to scale hypothesis to be tested is whether the economic contribution of digitization in the region is higher in Europe than that of less developed economies.

Data

The CAF Digital Ecosystem Development Index was calculated for Albania, Austria, Belgium; Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Georgia, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Latvia, Lithuania, Luxembourg, North Macedonia, Moldova, Montenegro, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom. The model included independent variables for fixed capital formation (source: World Bank), GDP per capita (source: IMF), the education index (source: United Nations Development Program), as a proxy for labour quality.

Model results and discussion

The model was run for all countries for the period 2010-2018, which resulted in 360 observations, and included fixed effects by year (see Table 7).

Table 7: Economic impact of digitization in the Europe region (2010-2018)

Variable	Coefficients
Previous GDP	0.5462 *** (0.0461)
Digitization	0.1359 ** (0.0590)
Capital	0.2049 *** (0.0516)
Labour	-0.4656 (0.2873)
Constant	3.2318 *** (0.4810)
Observations	360
Countries	40
Year fixed effects	Yes

***, **, * significant at 1%, 5%, and 10% critical value respectively.

According to the model in Table 7, an increase of 10 per cent in the CAF Digital Ecosystem Development Index results in a 1.36 per cent growth in GDP per capita. Therefore, an increase in the Digital Ecosystem Development Index from 50 to 51 will yield an increase of per capita GDP of 0.27 per cent (accounting both for direct and indirect effects on output).

The results from the Europe region model are in line with those of the digitization model for OECD countries, which exhibits a close coefficient (see Table 8).

Table 8: Economic impact of digitization, 2010-2018 (Europe region compared to OECD countries)

Variable	Europe	OECD countries
Previous GDP	0.5462 *** (0.0461)	0.6783 *** (0.0311)
Digitization	0.1359 ** (0.0590)	0.1351 * (0.0711)
Capital	0.2049 *** (0.0516)	0.2105 *** (0.0291)
Labour	-0.4656 (0.2873)	-0.0736 (0.0502)
Constant	3.2318 *** (0.4810)	2.3371 *** (0.3823)
Observations	360	374
Year fixed effects	Yes	Yes

***, **, * significant at 1%, 5%, and 10% critical value respectively.

3.6 Impact of policy and regulatory framework on digitization in Europe

The following analysis is based on the similar model used in the ITU 2018 global study to test the impact of the ITU ICT Regulatory Tracker on the CAF Digital Ecosystem Development Index in the Europe region.

Data

The models in this case rely on the ITU ICT Regulatory Tracker and the CAF Digital Ecosystem Development Index for the period from 2007 to 2018 for Albania, Austria, Belgium; Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Georgia, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Latvia, Lithuania, Luxembourg, North Macedonia, Moldova, Montenegro, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom.

As indicated in the ITU 2018 global study, the CAF Digital Ecosystem Development Index includes an institutional and regulatory pillar that had to be excluded in order to avoid co-linearity[20]. Once this was done and the Index was recalculated, it was possible to test the impact of the ITU ICT Regulatory Tracker on digitization.

Model results and discussion

A correlational analysis of the ITU ICT Regulatory Tracker and the CAF Digital Ecosystem Development Index was run, with results presented in Table 9.

[20] The CAF Digital Ecosystem Development Index comprises eight pillars, of which one measures the development of institutional and regulatory framework in a given country (see Katz and Callorda, 2018a). If this last pillar were to be included in the measurement of the Index, it would be impossible to measure the effect of the ICT Regulatory Tracker on digitization, because of the high level of correlation between two variables that measure approximately the same phenomenon (a condition known as collinearity).

Table 9: Correlation between the ITU ICT Regulatory Tracker and the CAF Digital Ecosystem Development Index

CAF Digital Ecosystem Development Index (without the regulatory pillar)	Coefficient (standard deviation) Europe
ITU ICT Regulatory Tracker	0.88723 *** (0.03432)
Constant	-17.53862 *** (2.86328)
R-square	0.6035
Fixed effects for year and country	Yes
Countries	40
Observations	480
Years	2007-2018

***, **, * significant at 1%, 5%, and 10% critical value respectively.

In order to test for the causal link, a control of a one-year lag of the ITU ICT Regulatory Tracker was also added (see Table 10).

Table 10: Impact of the lagged ITU ICT Regulatory Tracker on the CAF Digital Ecosystem Development Index

CAF Digital Ecosystem Development Index (without the regulatory sub-index)	Coefficient (Standard deviation) Europe
ITU ICT Regulatory Tracker (t)	0.45949 *** (0.06437)
ITU ICT Regulatory Tracker (t-1)	0.46441 *** (0.05625)
Constant	-19.40187 *** (2.98031)
R-squared	0.6456
Fixed effects for year and country	Yes
Groups	40
Observations	440
Years	2008-2018

***, **, * significant at 1%, 5%, and 10% critical value respectively.

In this model, it was found that an additional point in the ITU ICT Regulatory Tracker yields 0.45949 points higher in the CAF Digital Ecosystem Development Index (without the regulatory sub-index) in the same period and 0.46441 higher in the subsequent period, which, by adding both effects yields a total coefficient of 0.92390.

Previous models tested the correlation between both indices, and the model was also run through logarithms of all variables to assess the rate of change. The CAF Digital Ecosystem Development Index was also recalculated without the regulatory and the competition pillars (since, as indicated above, the potential co-linearity with the ITU ICT Regulatory Tracker is high) (see Table 11).

Table 11: Impact of the lagged ITU ICT Regulatory Tracker on the CAF Digital Ecosystem Development Index

Log CAF Digital Ecosystem Development Index (without the regulatory and competition pillars)	Coefficient (Standard deviation) Europe
Log CAF Digital Ecosystem Development Index (without regulation and competition pillars) (t-1)	3.28556 *** (0.04868)
Log ITU ICT Regulatory Tracker (t-1)	0.06132 *** (0.01910)
Constant	-0.79144 *** (0.06398)
R-Squared	0.9561
Fixed effects for year and country	Yes
Groups	40
Observations	440
Years	2008-2018

***, **, * significant at 1%, 5%, and 10% critical value respectively.

In this case, an increase of 10 per cent in the ITU ICT Regulatory Tracker yields a positive increase in the CAF Digital Ecosystem Development Index of 0.613 per cent in the subsequent time period.

In order to further test the relationship between the regulatory and the digital ecosystem indices, a set of alternative regressions between pillars of both indices was run (see Table 12).

Table 12: Regression between ITU ICT Regulatory Tracker and CAF Digital Ecosystem Development Index pillars

Pillars	ITU ICT Regulatory Tracker	ITU ICT Regulatory Tracker (without Competition)	Regulatory authority component	Regulatory mandate component	Regulatory regime component	Competition framework component
CAF Digital Ecosystem Development Index	**1.0305 (0.0511) *** **	**0.9945 (0.0430) *** **	0.4052 (0.0626) ***	**0.9329 (0.0787) *** **	0.5208 (0.0223) ***	**0.7640 (0.0570) *** **
Infrastructure of digital services	**1.6017 (0.0932) *** **	**1.5627 (0.0794) *** **	0.5190 (0.1087) ***	**1.4660 (0.1368) *** **	**0.8189 (0.0412) *** **	**1.1766 (0.1003) *** **
Connectivity of digital services	**1.2192 (0.0674) *** **	**1.1923 (0.0569) *** **	0.4000 (0.0801) ***	**1.1168 (0.1002) *** **	**0.6255 (0.0295) *** **	**0.9137 (0.0729) *** **

Pillars	ITU ICT Regulatory Tracker	ITU ICT Regulatory Tracker (without Competition)	Regulatory authority component	Regulatory mandate component	Regulatory regime component	Competition framework component
Household digitization	**1.4326 (0.0727) *****	**1.3797 (0.0616) *****	0.5621 (0.0883) ***	**1.2878 (0.1114) *****	**0.7204 (0.0321) *****	**1.0542 (0.0808) *****
Digitization of production	**0.7726 (0.0455) *****	**0.7026 (0.0409) *****	0.5546 (0.0473) ***	0.5621 (0.0697) ***	0.3635 (0.0214) ***	0.5605 (0.0491) ***
Digital competitive intensity	0.3199 (0.0456) ***	0.3422 (0.0402) ***	-0.0129 (0.0444)	0.2912 (0.0597) ***	0.1809 (0.0209) ***	0.2894 (0.0437) ***
Development of digital industries	**1.4157 (0.0968) *****	**1.3743 (0.0841) *****	0.5114 (0.1064) ***	**1.3120 (0.1369) *****	**0.7218 (0.0436) *****	**1.0264 (0.1014) *****
Digital factors of production	**1.3454 (0.0887) *****	**1.3184 (0.0764) *****	0.4300 (0.0992) ***	**1.1730 (0.1279) *****	**0.6976 (0.0394) *****	**1.0047 (0.0929) *****

***, **, * significant at 1%, 5%, and 10% critical value respectively.

NOTE: The values in bold have a relationship higher than 0.60. All the regression models include fixed effects by country and year.

A second set of regressions shows that the regulatory regime component of the ITU ICT Regulatory Tracker appears to be the main path of impact of the CAF Digital Ecosystem Development Index (see table 13).

Table 13: Impact of the ITU ICT Regulatory Tracker components on the CAF Digital Ecosystem Development Index pillars

	CAF Digital Ecosystem Development Index	Infrastructure of digital services	Connectivity of digital services	Household digitization	Digitization of production	Digital competitive intensity	Development of digital industries	Digital factors of production
Regulatory authority component	-0.4960 (0.0546) ***	-0.9967 (0.0990) ***	-0.7543 (0.0698) ***	-0.6827 (0.0791) ***	0.1743 (0.0563) ***	-0.4469 (0.0515) ***	-0.7843 (0.1102) ***	-0.8532 (0.0968) ***
Regulatory mandate component	0.1135 (0.0757)	0.2310 (0.1372) *	0.1692 (0.0968) *	0.1514 (0.1096)	-0.2106 (0.0781) ***	0.0488 (0.0715)	0.2157 (0.1528)	0.0616 (0.1341)
Regulatory regime component	0.6600 (0.0313) ***	1.0978 (0.0568) ***	0.8380 (0.0401) ***	0.9132 (0.0454) ***	0.3566 (0.0323) ***	0.3195 (0.0296) ***	0.9330 (0.0633) ***	0.9699 (0.0555) ***
Constant	3.0443 (0.1809) ***	2.4767 (0.3278) ***	3.2367 (0.2313) ***	2.5684 (0.2619) ***	3.2357 (0.1866) ***	4.3626 (0.1708) ***	2.0618 (0.3650) ***	3.0192 (0.3205) ***
R-squared	0.6241	0.5726	0.6100	0.6021	0.4139	0.2716	0.4475	0.5054

***, **, * significant at 1%, 5%, and 10% critical value respectively.

Table 13 indicates that the *regulatory regime* component always[21] has a positive and significant impact on each pillar of the digital ecosystem development index[22]. This suggests that the regulatory regime component has a higher impact on digital development[23] in the Europe region countries and is critical in driving digitization, reflecting a need for regulators to focus on this component to maximize the impact of regulation on ICT development.

4 Conclusion

This study tested the findings of the ITU global study on the economic contribution of broadband and digitization, as well as the impact of regulation and policy on the digital economy in countries in the ITU Europe region.

An assessment of the research literature on the economic contribution of broadband in the Europe region reflected the findings of the ITU 2018 global study and confirmed the following effects for Europe region countries:

- The economic impact of fixed broadband for high-income countries is substantially higher than low-income countries in the region (returns to scale effect).
- The economic impact of mobile broadband is higher among low-income countries than in high-income Europe region countries (saturation effect).
- The economic impact of digitization in Europe region countries is close to that of the OECD nations in the ITU 2018 global study (returns to scale effect).

The evidence yielded by the econometric analyses presented above confirms the hypotheses (see Table 14).

[21] The only exception is the Digital Competitive Intensity for the Regulatory Regime Component; and Development of Digital Industries for the Regulatory Mandate Component.

[22] The regulatory regime component includes indicators such as type of licenses provided to offer telecommunications services, obligations to publish interconnection offers by operators, monitoring of quality of service, infrastructure sharing for mobile operators permitted and/or mandated, unbundled access in local loop, spectrum secondary trading allowed, and number portability.

[23] While the first component of the ICT Regulatory has sometimes a negative sign, the coefficient of regulatory regime and regulatory mandate is always bigger and positive.

Table 14: Summary of results of econometric models (Europe region compared to ITU 2018 global study)

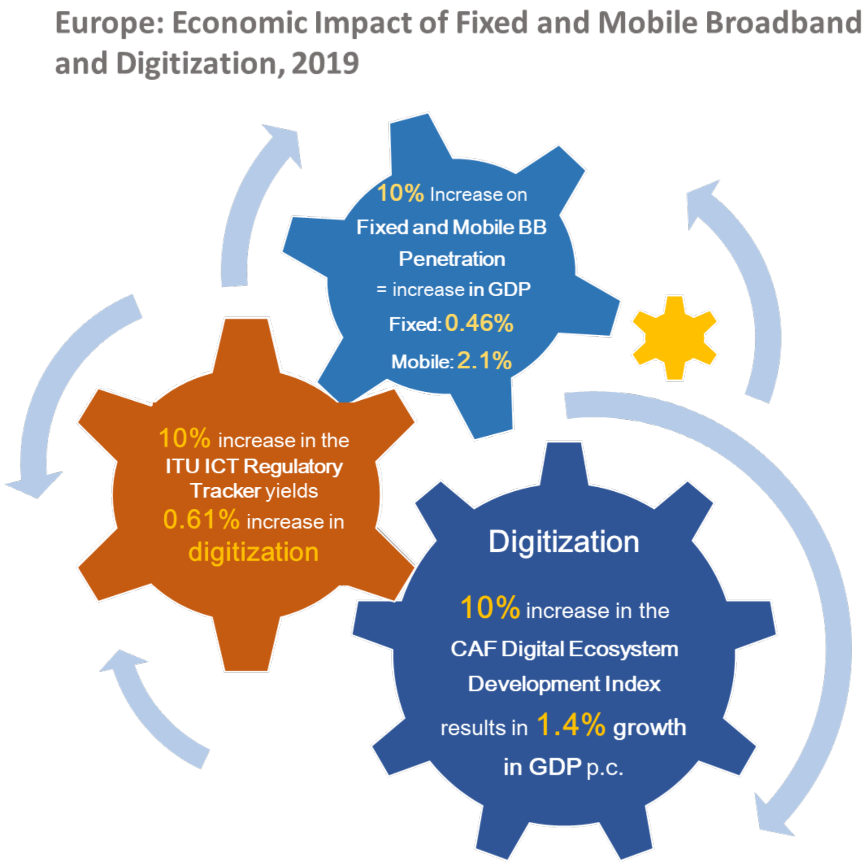
Hypothesis	Coefficient of 10% increase impact in penetration on GDP per capita growth					
	Aggregate Europe region	High-income Europe region	Low-income Europe region	ITU global study	ITU global study – High income countries	ITU global study – Low-income countries
Economic impact of fixed broadband in high-income countries in the ITU Europe region is higher than the impact estimated for low-income countries (returns to scale effect)	0.4	2.9	0.07 (not significant)	0.8	1.4	0.5 (not significant)
Economic impact of mobile broadband in low-income countries in the ITU Europe region is higher than high income countries (saturation effect)	2.1	-0.2 (not significant)	2.0	1.5	-0.2 (not significant)	2
Economic impact of digitization in the ITU Europe region is as high as that of OECD high-income countries (returns to scale effect)	1.36			1.33	1.35 (OECD countries)	1 (non-OECD countries)

In summary, the coefficient of economic impact of fixed broadband in the ITU Europe region high-income countries (2.9) is higher than that of European low-income countries (0.07, although not significant) and higher than high-income countries in the global sample (1.4).

The coefficient of economic impact of mobile broadband for the high-income countries in the ITU Europe region is not significant while that for low-income countries is positive (2.0) and statistically significant. The economic impact of digitization is as high for the ITU Europe region countries as it is for OECD countries due to the weight that high-income countries have overall for the region.

The main conclusions of the Europe analyses are represented in Figure 1.

Figure 1: Main findings for the Europe region



Source: ITU

The impact of policy and regulatory frameworks on the development of digitization was also tested. In the case of the Europe region, the results also validated the positive impact of the policy and regulatory variable. It was noted that an increase of 10 per cent in the ITU ICT Regulatory Tracker yields a positive increase in the CAF Digital Ecosystem Development Index of 0.61 per cent in the Europe region countries. A second set of regressions shows that of all the components of the ITU ICT Regulatory Tracker, the regulatory regime component appears to be the main path of impact of the CAF Digital Ecosystem Development Index. This analysis provided further evidence of the importance of the regulatory and institutional variable in driving the digital ecosystem growth.

Annex A: List of data sources for models testing the economic impact of fixed and mobile broadband

Indicator	Source
GDP per capita	IMF
Fixed broadband subscriber penetration	ITU- OVUM
Capital- Gross capital formation (percentage of GDP)	World Bank
Education- School enrolment, tertiary (per cent gross)	World Bank
Fixed telephone subscribers	ITU
Rural population (per cent of total population)	World Bank
Fixed broadband price	ITU
HHI fixed broadband	OVUM
Fixed broadband revenue	ITU- OVUM
Mobile broadband unique subscriber penetration	GSMA
Mobile unique subscriber penetration	GSMA
Mobile broadband price/ARPU	ITU- GSMA
HHI mobile broadband	GSMA
Mobile broadband revenue	GSMA

Annex B: Indicators included in Digital Ecosystem Development Index and data sources

Pillar	Sub-pillar	Indicator	Source
Infrastructure	Investment	Telecommunications investment per capita in current prices – five-year average (USD PPP)	World Bank; ITU
Infrastructure	Quality of service	Average fixed broadband download speed (Mbit/s)	Akamai
Infrastructure	Quality of service	Average mobile broadband download speed (Average Mbit/s)	Akamai
Infrastructure	Quality of service	Fixed broadband connections with download speed higher than 4 Mbit/s (percentage)	Akamai
Infrastructure	Quality of service	Fixed broadband connections with download speed higher than 10 Mbit/s (percentage)	Akamai
Infrastructure	Quality of service	Fixed broadband connections with download speed higher than 15 Mbit/s (percentage)	Akamai
Infrastructure	Quality of service	Optical fibre broadband connections as a percentage of total fixed broadband connections	ITU; FTTH; OECD
Infrastructure	Quality of service	International broadband bandwidth per Internet user (bit/s)	ITU
Infrastructure	Coverage	Fixed broadband coverage (% of households)	Eurostat, CAF Ideal; OECD
Infrastructure	Coverage	2G coverage	ITU
Infrastructure	Coverage	3G coverage	ITU
Infrastructure	Coverage	4G coverage	ITU
Infrastructure	Service infrastructure	IXPs per 1 000 000 population	Packet Clearing House; UNCTAD
Infrastructure	Service infrastructure	Number of secure servers (per 1 000 000 population)	World Bank
Infrastructure	Service infrastructure	Number of satellites (per 1 000 000 population)	N2yo.com
Connectivity	Affordability	Monthly fixed broadband subscription as percentage of GDP per capita	ITU
Connectivity	Affordability	Monthly mobile broadband Smartphone subscription (500 MB cap, prepaid) as percentage of GDP per capita	ITU
Connectivity	Affordability	Monthly mobile broadband PC subscription (1 GB cap, postpaid) as percentage of GDP per capita	ITU
Connectivity	Affordability	Monthly pay TV subscription as percentage of GDP per capita	Business Bureau; CAF; PwC; TAS

Pillar	Sub-pillar	Indicator	Source
Connectivity	Penetration	Fixed broadband penetration (connections per 100 households)	ITU
Connectivity	Penetration	Mobile broadband penetration (connections per 100 population)	ITU
Connectivity	Penetration	Unique mobile broadband users (per 100 population)	GSMA
Connectivity	Penetration	Pay TV penetration (connections per 100 households)	Business Bureau; CAF; PwC; TAS; ITU; Convergencia
Connectivity	Ownership	Penetration of computers (% of households)	ITU
Connectivity	Ownership	Smartphone users (per 100 population)	GSMA
Connectivity	Ownership	Percentage of population with access to electric energy	World Bank
Household digitization	Internet use	Percentage of population using the Internet	ITU
Household digitization	Internet use	Penetration of dominant social network (users per 100 population)	OWLOO
Household digitization	Internet use	Mobile data ARPU as percentage of total ARPU	GSMA
Household digitization	E-government	E-government index	ONU
Household digitization	E-commerce	Internet commerce as percentage of total retail commerce	Euromonitor
Household digitization	Telemedicine	National health policy (binary variables)	WHO
Household digitization	OTTs	Video on demand penetration (per cent households)	PWC
Digitization of production	Digital infrastructure	Per cent enterprises with Internet access	UNCTADstat; TAS; Eurostat
Digitization of production	Digital supply chain	Per cent enterprises using Internet for electronic banking	UNCTADstat; TAS; Eurostats
Digitization of production	Digital supply chain	Per cent enterprises using Internet for purchasing inputs	UNCTADstat; TAS; Eurostat
Digitization of production	Digital distribution	Per cent enterprises that sell products over the Internet	UNCTADstat; TAS; Eurostat
Digitization of production	Digital processing	Per cent workforce using the Internet	UNCTADstat; TAS; Eurostat
Digitization of production	Digital processing	Per cent workforce using computers	UNCTADstat; TAS; Eurostat

Pillar	Sub-pillar	Indicator	Source
Competitive intensity	Competition level	HHI fixed broadband	Convergencia; Regulators; TAS
Competitive intensity	Competition level	HHI mobile broadband	GSMA; Regulators
Competitive intensity	Competition level	HHI pay TV	Convergencia; Dataxis; Ofcom; TAS; Regulatory entities
Competitive intensity	Competition level	HHI mobile telephony	GSMA; Regulators
Digital industries	Exports	High technology exports (USD per capita in current prices)	World Bank
Digital industries	Exports	ICT services exports (USD per capita in current prices)	World Bank
Digital industries	Weight of digital industries	Digital ecosystem sales as a percentage of GDP	PWC; TAS; ITU
Digital industries	Weight of digital industries	Telecommunications operators revenues per capita (USD in current prices)	ITU
Digital industries	Weight of digital industries	Computer software spending (per cent of GDP)	INSEAD
Digital industries	Internet of Things	M2M connections (per 100 population)	ITU; OECD
Digital industries	Content production	Wikipedia pages edited per month (per million population between 15 and 69 years old)	INSEAD
Factors of digital production	Human capital	Education years expectancy (years)	World Bank; UNESCO
Factors of digital production	Human capital	Tertiary school enrolment (per cent population)	World Bank; UNESCO
Factors of digital production	Schools	Per cent educational establishments with Internet access	UNESCO; ECLAC
Factors of digital production	Schools	Computers per student ratio	UNESCO; ECLAC
Factors of digital production	Innovation	USPTO patents per country (per 1 000 000 population)	USPTO
Factors of digital production	Innovation	Intellectual property revenues (USD per capita PPA in current prices)	World Bank
Factors of digital production	Investment in innovation	R&D spending (per cent of GDP)	World Bank; UNESCO
Factors of digital production	Economic development	GDP per capita (USD current prices)	IMF
Factors of digital production	Economic development	Electric energy consumption (kWh per capita)	World Bank

Pillar	Sub-pillar	Indicator	Source
Institutional and regulatory	Cyber-security and piracy	Per cent of non-licensed installed software	BSA, The software alliance
Institutional and regulatory	Cyber-security and piracy	Commercial value of non-licensed software (as per cent of GDP)	BSA, The software alliance
Institutional and regulatory	Government role	Per cent of regulatory agency attributions based on ITU regulatory tracker	ITU; TAS
Institutional and regulatory	Government role	Per cent of regulatory agency functions based on ITU regulatory tracker	ITU; TAS
-	-	Population	World Bank
-	-	Exchange rate PPP	IMF
-	-	Number of households	ITU
-	-	GDP per capita for first quintile (USD in current prices)	IMF; World Mundial

Annex C: Econometric modelling

The econometric models described in this annex is the same as the one used for the ITU 2018 global study the economic contribution of broadband, digitization and ICT regulation[24].

Economic contribution of fixed and mobile broadband

The State-of-the-art econometric models currently in use consist of four equations: an aggregate production function modelling the economy and, subsequently, three functions: demand, supply and output[25].

In the case of mobile telecommunications, for example, the last three functions model the mobile market operation and, controlling for the reverse effects, the actual impact of the infrastructure, as follows:

1. In the production function, GDP is linked to the fixed stock of capital, labour and the mobile infrastructure proxied by mobile penetration.
2. 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 per cent rural population, and the level of competitive intensity in the mobile market measured by the HHI (Herfindahl Hirschman) index.
3. 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 output equation links annual change in mobile penetration to mobile revenues, used as a proxy of the capital invested in a country in the same year. The econometric specification of the model is:

Aggregate Production function: (1)

$$GDP_{it} = a_1K_{it} + a_2L_{it} + a_3Mob\_Pen_{it} + e_{it}$$

Demand function: (2)

$$Mob\_Pen_{it} = b_1Rural_{it} + b_2Mob\_Price_{it} + b_3GDPC_{it} + b_4HHI_{it} + e_{it}$$

Supply function: (3)

$$Mob\_Rev_{it} = c_1MobPr_{it} + c_2GDPC_{it} + c_3HHI_{it} +$$

Output function: (4)

$$\Delta Mob\_Pen_{it} = d_1Mob\_Rev_{it} + \varepsilon 4_{it}$$

In order to test the current economic impact of telecommunication technology, two models were constructed (one for fixed broadband and another one for mobile broadband) and specify them

24 Extracted from the ITU Global study The economic contribution of broadband, digitization and ICT regulation (https://www.itu.int/en/ITU-D/Regulatory-Market/Documents/FINAL_1d_18-00513_Broadband-and-Digital-Transformation-E.pdf).

25 Originally developed by Roller and Waverman (2001) and implemented by Koutroumpis (2009), Katz and Koutroumpis (2012a; 2012b), and Katz and Callorda (2014; 2016; 2018).

for two cross-sectional samples of countries. This methodology would allow the three hypotheses explained above to be tested while controlling for endogeneity effects[26].

Economic impact of digitization

Digitization, as a social process, refers to the transformation of the techno-economic environment and socio-institutional operations through digital communications and applications. Unlike other technological innovations, digitization builds on the evolution of network access technologies (mobile or fixed broadband networks), semiconductor technologies (computers/laptops, wireless devices/tablets), software engineering (increased functionality of operating systems) and the spillover effects resulting from their use (common platforms for application development, electronic delivery of government services, electronic commerce, social networks, and availability of online information in fora, blogs and portals). In order to measure the economic impact of digitization it is necessary to develop metrics that determine a country's level of digital eco-system development.

Theoretical framework and review of the research literature

The study of a country or region stage of development in the adoption of ICTs (information and communication technologies) has been progressing over the last twenty years. While the original focus was to assess the deployment and adoption of telecommunication and information technology infrastructure (broadband, mobile telephony, computers), research has been gradually expanding its focus to include dimensions such as the use of digital technologies (electronic commerce, electronic government, social networks) as well as the development of industries within the full digital value chain (Internet platforms, collaborative Internet services, etc.). In this process, a number of indices have been developed along the way, including the International Telecommunication Union ICT Development Index, the World Bank Knowledge Economy Index, the World Economic Forum Network Readiness Index, and the Inter-American Development Bank Broadband Development Index. However, most of the indices developed so far tend to either address a particular aspect of the digital ecosystem, such as broadband penetration, or include a limited number of indicators.

For the application of this methodology an endogenous growth model was used, which links GDP to the fixed stock of capital, labour force, and the digitization index as a proxy of technology progress. This model for economic output stems from the simple Cobb-Douglas form:

$$Y = A_{(t)} K^{1-b} L^{b}$$

where

$A_{(t)}$ represents the level of technology progress (in our case the digitization index),

K corresponds to the fixed capital formation, and

L to the labour force.

By converting all terms to logarithms, the coefficients can be estimated through an econometric model.

$$log(GDP_{it}) = a_1 log(k_{it}) + a_2 log(L_{it}) + a_3 log(D_{it}) + \varepsilon_{it}$$

Since the development of the original digitization index, a number of changes occurred within this phenomenon, adding complexity that was not accounted for in the original index. For example, **the**

[26] As explained by Roller and Waverman, "This approach uses all the exogenous variable in the system of equations (i.e., those that can reasonably be assumed are not determined by the other variables in the system, such as the amount of labour and the amount of total capital) as "instruments" for the endogenous variables (output, the level of penetration, and the prices). Instrumenting the endogenous variables essentially involves isolating that component of the given endogenous variable that is explained by the exogenous variables in the system ("the instruments") and then using this component as a regressor."

development of the infrastructure of digital services provides individuals, businesses and public organizations access to digital content and services. It also supplies interconnectivity to players within the digital value chain (e.g. developers of digital content, Internet platforms, etc.) so they can deliver a value proposition to users[27].

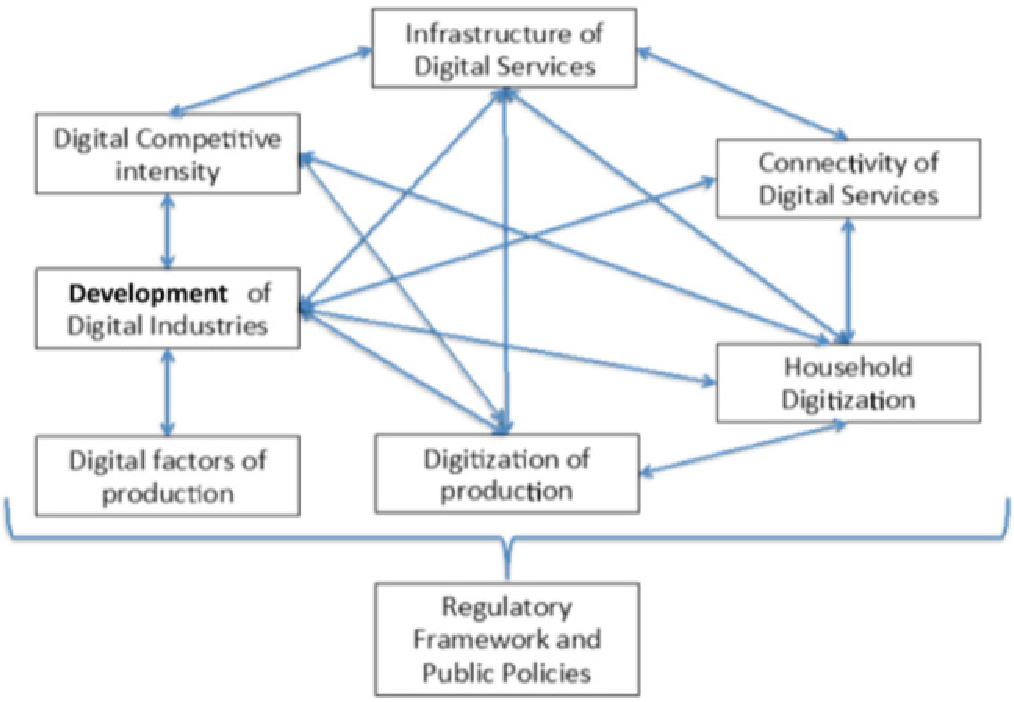
Digital connectivity measures the adoption of terminals (computers, smartphones) and services (broadband, wireless telephony) in order to allow individuals and organizations to gain access to networks. Network access enables the use of digital products and services, which is defined as digitization. This term is used to measure not only the use of digital services by individual consumers (**household digitization**) but also its assimilation by enterprises (**digitization of production)**.

The demand of digital products and services by individual consumers, enterprises and governments is met by the offer supplied by **digital industries** (which comprise Internet platforms, media companies, telecommunication operators, and equipment manufacturers, among others). These firms can be located within the country where demand is located or, enabled by virtual business models, can be based beyond its frontiers. In order to develop digital industries within a country, they require conventional **factors of production** ranging from human to investment capital.

Finally, for digital industries to generate static and dynamic consumer benefits, they need to operate within a sustainable **competitive environment**, and receive the appropriate incentives and controls embodied in a **regulatory framework and public policies**.

As a result, the digital ecosystem could be defined as a set of interconnected components (or pillars) operating within a socio-economic context. Figure below illustrates the correlations between the eight pillars of the original digital ecosystem development index, showing the strong interplay among them.

Figure 2: Conceptual structure of the digital ecosystem development index



Source: Katz and Callorda (2017)

Note: Links are drawn only for relatively strong causal relationships (see analysis below).

27 Telecommunications services provide value insofar that they allow consumer access to the Internet.

In order to assess the existence and strength of the causal link between digital ecosystem development and economic development, an endogenous growth model based on the Cobb-Douglas production function was specified linking the stock of fixed capital, labour force, and the digital ecosystem development index. The model also controls for GDP per capita for previous year to account for inertia effects:

$$Y_{(t)} = A_{(t)} K_{(t)}^{1-b} L_{(t)}^{b}$$

By converting all equation terms to logarithms, the level of impact of each independent variable of the growth of the digital ecosystem was estimated:

$$\log (GDP_{it}) = a_1 \log (K_{it}) + a_2 \log (L_{it}) + a_3 \log (A_{it}) + \varepsilon_{it}$$

Where:

$K_{(t)}$ measures the level of fixed capital formation

$L_{(t)}$ measures labour force

$A_{(t)}$ measures the digital ecosystem development index

In this model, since both the dependent and independent variables are indices, the analysis is essentially correlational. In that sense, from a policy standpoint, if regulation improves in a given country, the digital ecosystem is expected to grow as well. The reverse causality hurdle is partly addressed by measuring how the rate of change in the ICT regulatory tracker affects the rate of development of the digital ecosystem.

Economic impact of policy and regulatory framework on the growth of markets for digital service

The analysis of the economic impact of policy and regulatory framework on the growth of markets for digital service relies on the ITU ICT regulatory tracker as the independent variable to test its impact on the digital ecosystem development index. For this purpose, two models were developed initially: the first tests the correlation between the ICT regulatory tracker and the digital ecosystem development index. The underlying premise is that higher regulatory performance is directly related to the development of the digital economy:

$$Dig.Index_{it} = \beta_1 Reg.Index_{it} + Year\ F.E. + Country\ F.E. + e_{it}$$

Beyond measuring the correlation between both variables, a model with lagged variables was developed. In this case, the specified model is as follows:

$$Dig.Index_{it} = \beta_1 Reg.Index_{it} + \beta_2 Reg.Index_{it-1} + Year\ F.E. + Country\ F.E. + e_{it}$$

Finally, the variables were converted to logarithms to test causality of change in values of both indices:

$$In\ (Dig.Index_{it}) = \beta_1 In\ (Dig.Index_{it}) + \beta_2 In\ (Dig.Index_{it-1}) + Year\ F.E. + Country\ F.E. + e_{it}$$

Furthermore, one cannot detect in this analysis a component of the ICT regulatory tracker that has higher importance than the rest when correlated with the digital ecosystem development index and its pillars. It is clear that growth in the ICT regulatory tracker components go in tandem with an improvement in all pillars of the digital ecosystem. A second set of regressions showed that the regulatory regime component of the ICT regulatory tracker appears to be the main path of impact of the digital ecosystem development index.

ICT regulatory tracker and digital ecosystem development index pillars

ICT Regulatory Tracker	ICT regulatory tracker (w/o Competition component)	Regulatory authority component	Regulatory mandate component	Regulatory regime component	competition framework		
Digital ecosystem development index	Infrastructure of Digital Services	Connectivity of Digital Services	Household digitization	Digitization of production	Digital Competitive Intensity	Development of Digital Industries	Digital factors of production

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