HOW BROADBAND, DIGITIZATION AND ICT REGULATION IMPACT THE GLOBAL ECONOMY

Global Econometric Modelling – Expert Report

GSR-20 Discussion Paper

August 2020

Acknowledgements

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This study is based on extensive compilation and analysis of statistical data from national and international sources and on data from the ITU ICT Regulatory Tracker and the Digital Ecosystem Development Index, developed with funding from CAF (Corporación Andina de Fomento) Development Bank for Latin America.

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Executive summary: how broadband and digitization impact the global economy

This study uses econometric modelling to examine *two major components* of great importance to all those concerned with investment decisions in ICT and the digital ecosystem over the coming decade. The modelling is built on data from 139 countries between 2007 and 2018 – an up-to-date data set that is robust, high-quality and global in scope.

The first component we examine is how broadband and digitization impact the economy. The second is how institutional and regulatory maturity impact the growth of the digital ecosystem.

Four major findings

Our evidence points to four major findings which we believe are of great import in informing governments, policy-makers, regulators and operators as they formulate general infrastructure and ICT investment decisions in the years ahead. The findings are:

1. Developing countries should implement policies to maximize mobile broadband adoption, as the main digital technology contributing to economic development.
2. Industrialized nations should adopt policies which favour fixed broadband penetration as a key contributor to their economic growth.
3. Beyond broadband, all countries should aim to increase the development of digitization, which encompasses not only infrastructure deployment but its usage to foster the digital transformation of industries and improve consumer wellbeing.
4. Regulatory and institutional maturity in the ICT arena do indeed make a significant difference – and are important in driving the growth of digitization.

The study confirms that the economic impact of fixed broadband is guided by a return to scale effect: *economic impact grows with penetration*. The economic benefit of mobile broadband depicts a saturation effect: *its economic contribution declines with penetration*.

Developing countries – accelerate your development of mobile broadband

Developing countries should accelerate the development of mobile broadband to maximize economic impact. Penetration of mobile broadband in OECD countries is at 74 per cent in terms of unique subscribers – but comparable figures for Africa are 31 per cent, for Latin America 57 per cent and for Asia Pacific 52 per cent.[1] Since we have found that economic impact of mobile broadband is higher in developing countries, such countries should maximize its adoption.

Six concrete steps for developing country governments to consider:

- <u>Policy and regulation</u>. Encourage policy and regulatory measures that facilitate infrastructure deployment in rural and isolated areas: these include the sharing of infrastructure, interconnectivity, and effective use of spectrum.
- <u>Emerging technologies.</u> Promote the use of emerging technologies to address the need for affordable digital infrastructure and services.
- <u>Incentives and collaboration</u>. Promote deployment of mobile broadband infrastructure in remote and rural areas through incentives that are attractive to private sector operators. Stimulate collaboration between private sector firms within your digital ecosystem.

[1] Source: Prorated GSMA Intelligence figures for 2020.

- Affordable pricing. Focus on mobile broadband affordability of non-adopters: implement government initiatives that drive affordable pricing for your most vulnerable populations.
- Content of importance and relevance to your citizens. Complement economic-focused efforts by promoting the development of local Internet content and languages.
- Skill up your non-adopters. Focus on building the digital skills of non-adopters to address digital illiteracy.

Industrialized countries – focus on technologies that boost digitization of your production

Industrialized nations should focus on technologies that accelerate the digitization of production: these include ultra-broadband wireline (FTTx and DOCSIS 3.1) and 5G – critical infrastructure technologies that enhance digitization of production, which will in turn boost economic impact. OECD countries have reached 5G coverage of 39 per cent[2] while FTTx household penetration is at 21 per cent.[3]

Seven concrete steps for developed countries to consider:

- Grow infrastructure and demand. Promote commercial and investment cases that combine the benefits of telecommunications infrastructure with other enabling technologies (e.g. AI, AR/VR) to grow infrastructure and ICT demand from enterprises.
- Use regulatory sandboxes enabling enterprises to test emerging technologies and use cases free of regulation.
- Spectrum allocation and new services. Launch 5G pilot projects to obtain feedback and to support design of future spectrum allocations – at the same time stimulating the adoption of new services.
- Balance new technologies with re-skilling. Recognize that advanced technologies can eliminate jobs. As you move to the digital transformation of production, ensure digital skills requirements are identified and retraining taken into account.
- Flexibility in regulation. Keep enough flexibility on regulatory rules and procedures (for example the use of spectrum) to foster innovation and new technologies.
- Long-term policies. Recognize that building infrastructure is a multi-year process that needs to be underpinned by long-term policies for predictability and regulatory certainty.
- Balance consumer protection with commercial returns. Recognize that competition models need to protect consumers, while ensuring adequate returns are available to commercial players making the investment.

[2] Source: Prorated GSMA intelligence 5G coverage for 2020.
[3] Source: Prorated IDATE FTTx penetration for 2019.

Addressing all countries – make regulation and ICT policy work for your economy

The paper clearly demonstrates that broadband technologies on one hand, and effective ICT regulation on the other, undoubtedly help grow national economies and the prosperity of the people.

All countries should leverage regulatory frameworks and institutions in accelerating digitization – forging sound ICT policy that maximizes economic impact within a simplified institutional architecture.

We recommend three specific policy approaches:

- Incorporate the economic impact of digitization in your assessment of policies. Policy-makers and regulatory agencies in all countries should integrate advanced socio-economic impact analysis into their policy development. Often, ICT policy-making takes only the engineering perspective into account. This task is best accomplished through close collaboration and partnership with academia and research institutions.
- Be collaborative and quick. Adopt a collaborative approach involving policy-makers, regulators and private operators. Build policy and regulation on principles of simplification and speed.
- Consult and be transparent. Allow for intense public participation and consultation with civil society as you build regulation. Give stakeholders the most transparent information.

The three focus areas for this paper

This paper uses global econometric analysis – based on robust, reliable data – to measure the impact of broadband (fixed and mobile) and digital transformation on the economy as a whole. It also examines how institutional and regulatory variables impact the development of the digital ecosystem at global level.

The study builds on previous ITU-published studies – using econometric modelling – that looked at how broadband, digitization and ICT regulation[4] contribute to the economy at the global and regional levels.

The study is built on three key analyses:

1. How fixed and mobile broadband are impacting the economy: Economic models, designed to explore how broadband contributed to the economy, have been developed primarily in the first decade of the 21st century. Are they still valid? This study brings fresh scrutiny to bear. On the basis of large data sets, the paper relies on long historical series and asks whether the economic boost of broadband increases with penetration – the so-called return to scale effect[5]… or is broadband's economic impact undergoing a "saturation effect"

[4] ITU's *The economic contribution of broadband, digitization and ICT regulation* and Regional Econometric Modelling Reports are available at: https://www.itu.int/en/ITU-D/Regulatory-Market/Pages/Economic-Contribution.aspx.

[5] 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 Broadband Series *Impact of Broadband on the Economy*, 2012 (https://www.itu.int/pub/D-

therefore yielding diminishing returns. Importantly, the analysis asks what the key differences are in how fixed and mobile broadband play in an economy, according to its level of development.

2. How digitization contributes to the economy: It's important to note that "digitization" is much broader in scope than broadband. It encompasses digital services infrastructure, connectivity, digital transformation both of households and production, the development of digital industries, and the availability of digital factors in production. So what is the impact of digitization on GDP and productivity when compared to broadband? The paper presents analysis of this question region by region.
3. How policy and regulatory frameworks affect market growth in digital services and applications**:** How exactly do regulation and institutions impact the development of the digital economy – *the transformation of the techno-economic environment and socio-institutional operations through digital communications and applications*. Given that growth of digitization is driven largely by the private sector, just how important are policy and regulatory variables in growing the digital economy?

PREF-BB.RPT2-2012) states that according to the returns to scale theory, the economic impact of broadband increases exponentially with the penetration of the technology.

At a glance: our seven key findings

Mobile broadband generates a **larger economic contribution** than fixed broadband, when examined globally.

Developing countries **benefit more from mobile broadband** than industrialized countries.

Developed countries with high penetration of fixed broadband enjoy **larger benefit from the technology** than developing nations.

The **economic contribution of digitization** is higher in advanced economies than in emerging countries.

Digitization contributes significantly to **labour** and total **factor productivity**.

The development of digitization is driven by **institutional and regulatory factors** and not only by variables such as economic development.

Digitization accelerates when a country introduces **structural changes in policy and institutions** which are related to digital technologies – after a time lag.

Fixed broadband and its impact on the economy

Developed countries, with high penetration of fixed broadband, realize larger benefit from the technology than developing nations. The impact is driven by a "*return to scale*"*:*

- When fixed broadband penetration is low, economic impact is minimal;
- But – when fixed broadband infrastructure reaches a critical level of development, typical of developed countries, it starts to have a significant impact on the economy.[6]

Impact of fixed broadband at global and regional levels

We examined data for 139 countries between 2010 and 2017 (in some cases between 2007 and 2018, and for others between 2011 and 2017).

In each case, we ran identical econometric structural models, each using four equations[7]:

Aggregate production function	GDP per capita$_{it}$ = a_1(Capital$_{it}$)+a_2(Education$_{it}$)+a_3(Broadband_Penetration$_{it}$)+ e_{it} (1)
Demand function	Broadband_Penetration$_{it}$=b_1(Rural_population)$_{it)}$+b_2(Broadband_Price)$_{it}$+b_3(GDPC)$_{it}$+b_4 (HHI)$_{it}$+e_{it} (2)
Supply function	Broadband_Revenue$_{it}$=c_1(Broadband_Price)$_{it}$+$c_{2(}$GDP per capita)$_{it}$+c_3(HHI Fixed broadband)$_{it}$+ e_{it} (3)
Output function	ΔBroadband_Penetration$_{it}$ = d_1(Fixed_Broadband_Revenue$_{it}$)+ ε_{4it} (4)

- We ran the econometric model first *for all countries* and then *for distinct groups of countries* according to their level of development:
    - Countries with GDP per capita higher than USD 22K (50 countries)
    - Countries with GDP per capita between USD 12K and USD 22K (26 countries)
    - Countries with GDP per capita lower than USD 12K (63 countries)

- We also measured the economic impact of fixed broadband by region:
    - Africa (34 countries)
    - Americas (18 countries)
    - Arab States (14 countries)
    - Asia Pacific (18 countries)
    - Commonwealth of Independent States (8 countries)
    - Europe (38 countries)

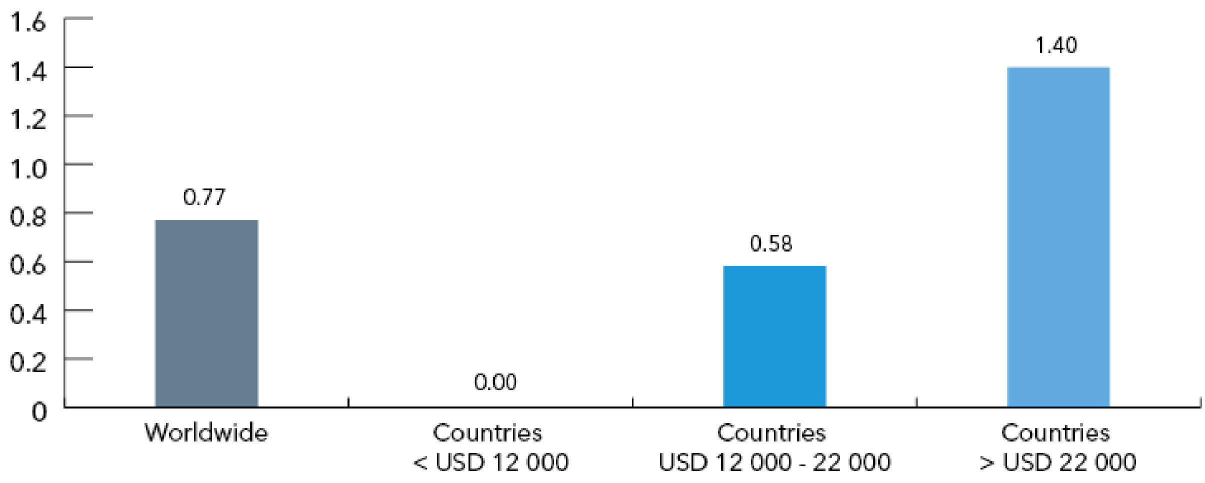
[6] This was already detected in early studies conducted with 2007 OECD data (see Czernich *et al*., 2009).

[7] As explained by Roller and Waverman (2001): "This approach uses all the exogenous variable in the system of equations (i.e., those that we can reasonably assume are not determined by the other variables in the system, such as the amount of labor 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."

Confirmed – globally, fixed broadband impact is higher in more developed countries

The econometric models run for the global sample confirm the "return to scale" effect: fixed broadband economic impact tends to increase with economic development (see Figure 1).

Figure 1: Global sample: GDP growth impact of an increase in 10% of fixed broadband penetration (in per cent)[8]

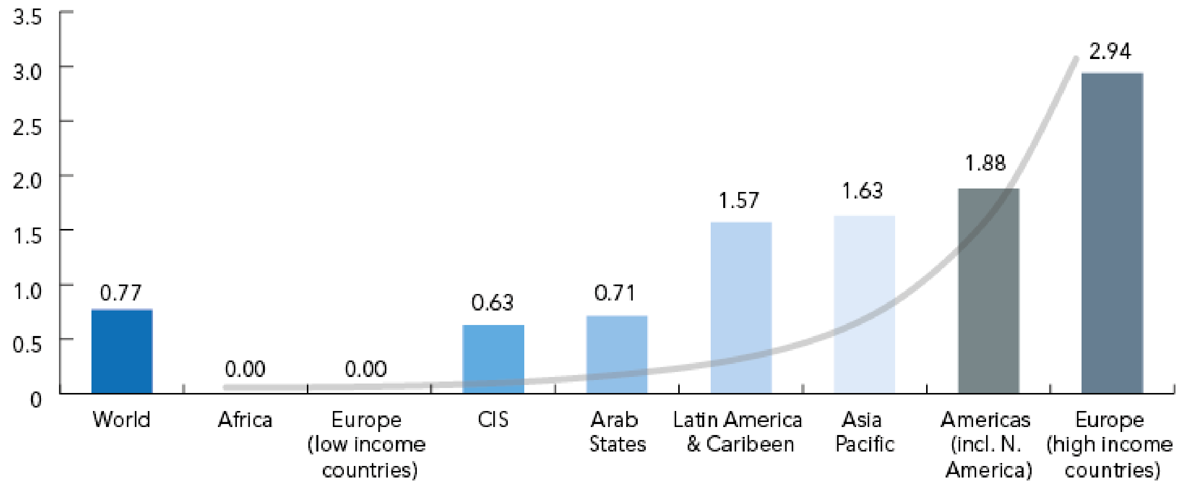


Note: The impact on countries with GDP per capita under USD 12 000 is not statistically significant.
Source: ITU publications on the Economic Contribution of Broadband, Digitization and ICT Regulation regional studies[9]

[8] Detailed results of econometric models are included in Appendix E.
[9] See: https://www.itu.int/en/ITU-D/Regulatory-Market/Pages/Economic-Contribution.aspx.

Models run by region tell the same story

Figure 2: Regional GDP growth impact of an increase in 10% of fixed broadband penetration (in per cent)



Source: ITU publications on the Economic Contribution of Broadband, Digitization and ICT Regulation regional studies

What the modelling showed by region

We applied econometric modelling to all of the world's regions. We assumed an increase of 10 per cent in fixed broadband penetration to calculate increase (or not) in GDP per capita. Our models suggested the following:

- Africa: most African countries would see no increase.
- Americas: countries across this region (North America and for Latin America and the Caribbean) would enjoy an increase of 1.88 per cent. Latin America and the Caribbean only would enjoy an increase of 1.57 per cent.
- Arab States: countries would enjoy an increase in 0.71 per cent.
- Asia Pacific: the entire region would enjoy an increase of 1.63 per cent while mid and low-income countries in the region would see no increase.
- Commonwealth of Independent States (CIS): the region increase in 0.63 per cent in GDP per capita.
- Europe: the results confirm that an increase of 10 per cent in fixed broadband penetration in high-income European countries would yield an increase in 2.94 per cent in GDP per capita. If only low-income European countries are included in the model, the impact is statistically not significant.

Mobile broadband and its impact on the economy

The economic contribution of mobile broadband is greater in countries and regions with lower levels of economic development and lower relative mobile penetration. The impact of mobile broadband is driven by a "saturation" or "diminishing returns" effect.[10]

Impact of mobile broadband at global and regional levels

The corollary is that the economic impact of mobile broadband diminishes in countries and regions with higher levels of penetration and development.

How is this explained? A number of factors are at play:

- Early broadband adopters (such as large enterprises and government services) gain most from mobile broadband, while late adopters (such as small and medium enterprises) will gain less.
- Incremental infrastructure deployment will *not* yield proportional gains where critical levels of telecommunication/ICT infrastructure and usage have already been attained.
- The national economic impact is at its maximum when telecommunications/ICT infrastructure investment has reached critical mass. Beyond that point, economic impact slows down, reflecting "diminishing returns".
- In countries with low fixed broadband penetration (i.e. low GDP per capita), mobile broadband is the technology with high economic impact – the "substitution effect".

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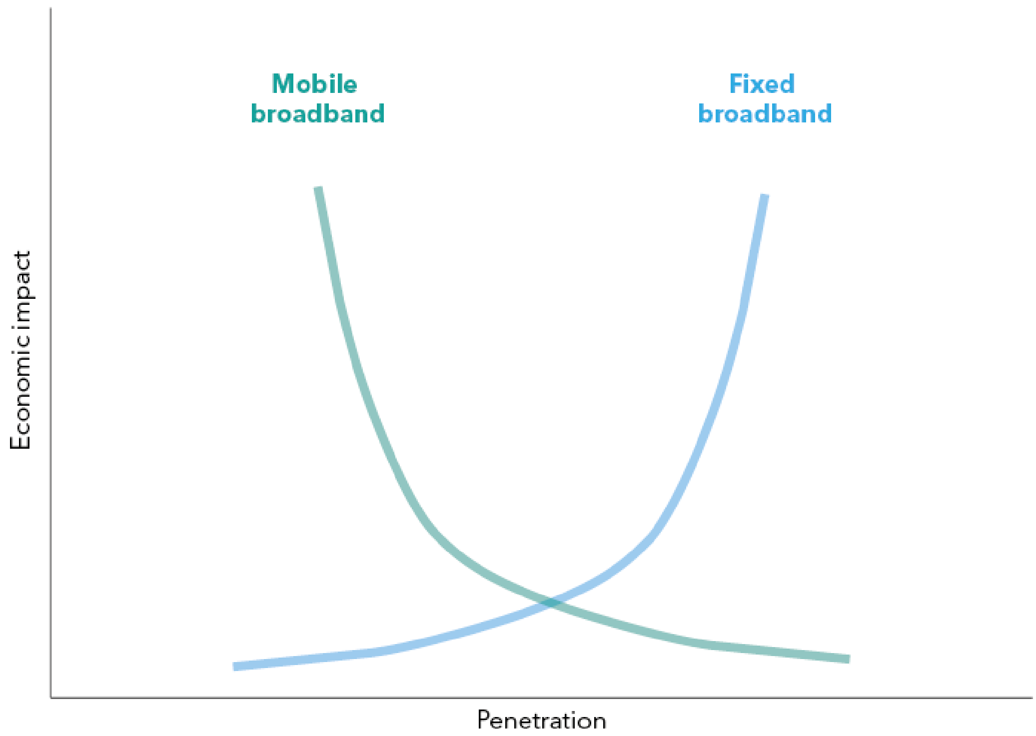
[10] In economics, diminishing returns is the decrease in the marginal (incremental) output of a production process as the amount of a single factor of production is incrementally increased, while the amounts of all other factors of production stay constant. In this case, we apply the concept to explain that the economic impact of mobile broadband decreases with penetration. We apply the concept of saturation to explain that, after a certain point in the diffusion process, no matter how much mobile broadband is adopted, no tangible economic effect will register.

Figure 3: Economic contribution – fixed versus mobile broadband



Source: ITU

Impact of mobile broadband declines as penetration levels increase

In economic terms, the impact of mobile broadband tends to decline with penetration. Governments should not however stand down policies aimed at stimulating its adoption: mobile broadband in many countries is the single most important technology that provides citizens and consumers with access to the Internet, thereby providing enormous social value.

The economic impact of mobile broadband – globally and by region

This study measured the economic impact of mobile broadband both at the global level and by region to test the "diminishing returns" effect. We looked at data for 139 countries between 2010 and 2017 (in some cases through 2018).

- We ran the econometric structural models (composed of four equations specified similar to the case of fixed broadband) to test the economic impact of mobile broadband:
    - For the global analysis, we relied on 3 858 observations between 2010 and 2017. For the regional analysis, we utilized a total of 4 061 observations between 2010 and 2018.
    - Models included country, year and fixed effects.

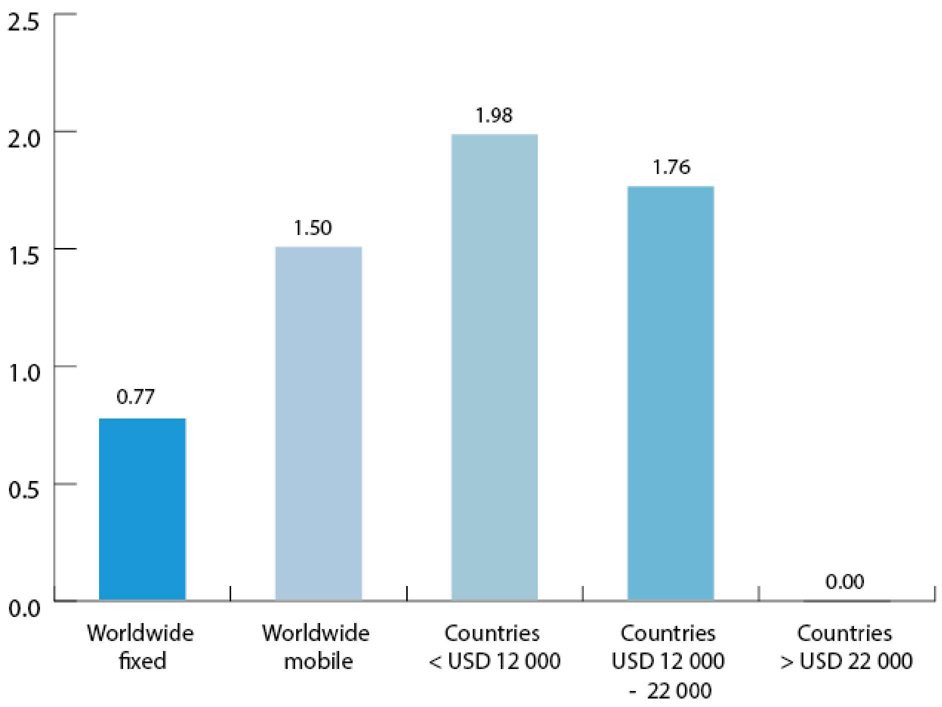
- We ran the econometric model first *for all countries* and then *for distinct groups of countries* according to their level of development:
    - Countries with GDP per capita higher than USD 22K (50 countries)

- Countries with GDP per capita between USD 12K and USD 22K (26 countries)
- Countries with GDP per capita lower than USD 12K (63 countries)

- We also measured the economic impact of mobile broadband by region:
  - Africa (34 countries)
  - Americas (18 countries)
  - Arab States (14 countries)
  - Asia Pacific (18 countries)
  - Commonwealth of Independent States (8 countries)
  - Europe (38 countries)

Globally, mobile broadband economic contribution is higher than fixed broadband, although impact decreases with economic development

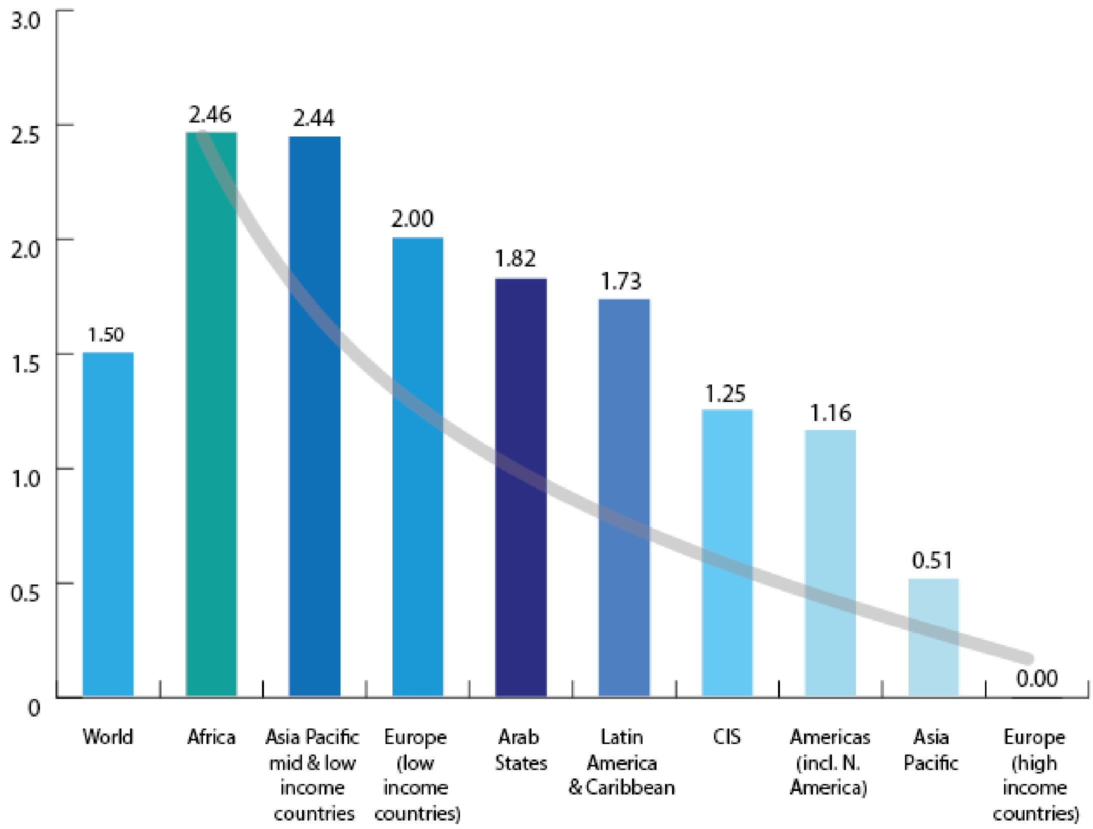
Figure 4: Global sample: growth impact of an increase in 10% of mobile broadband penetration (in per cent)



Source: ITU publications on the Economic Contribution of Broadband, Digitization and ICT Regulation regional studies

Regional analysis: developing economies benefit more from mobile broadband

Figure 5: Regional GDP growth impact of an increase in 10% of mobile broadband penetration (in per cent)



Source: ITU publications on the Economic Contribution of Broadband, Digitization and ICT Regulation regional studies

What the modelling showed by region

We applied econometric modelling to all of the world's regions. We assumed an increase of 10 per cent in mobile broadband penetration to calculate increase (or not) in GDP per capita. Our models suggested the following:

- Africa: the majority of countries would enjoy an increase of 2.46 per cent.
- The Americas: North America, Latin America and Caribbean would enjoy an increase of 1.16 per cent in GDP per capita. Latin America and the Caribbean countries only would enjoy an increase of 1.73 per cent.
- Arab States would enjoy an increase in 1.82 per cent in GDP per capita.
- Asia and Pacific countries overall would enjoy an increase of 0.51 per cent. Mid and low-income countries only would enjoy an increase of 2.44 per cent.
- Commonwealth of Independent States would enjoy an increase of 1.25 per cent.

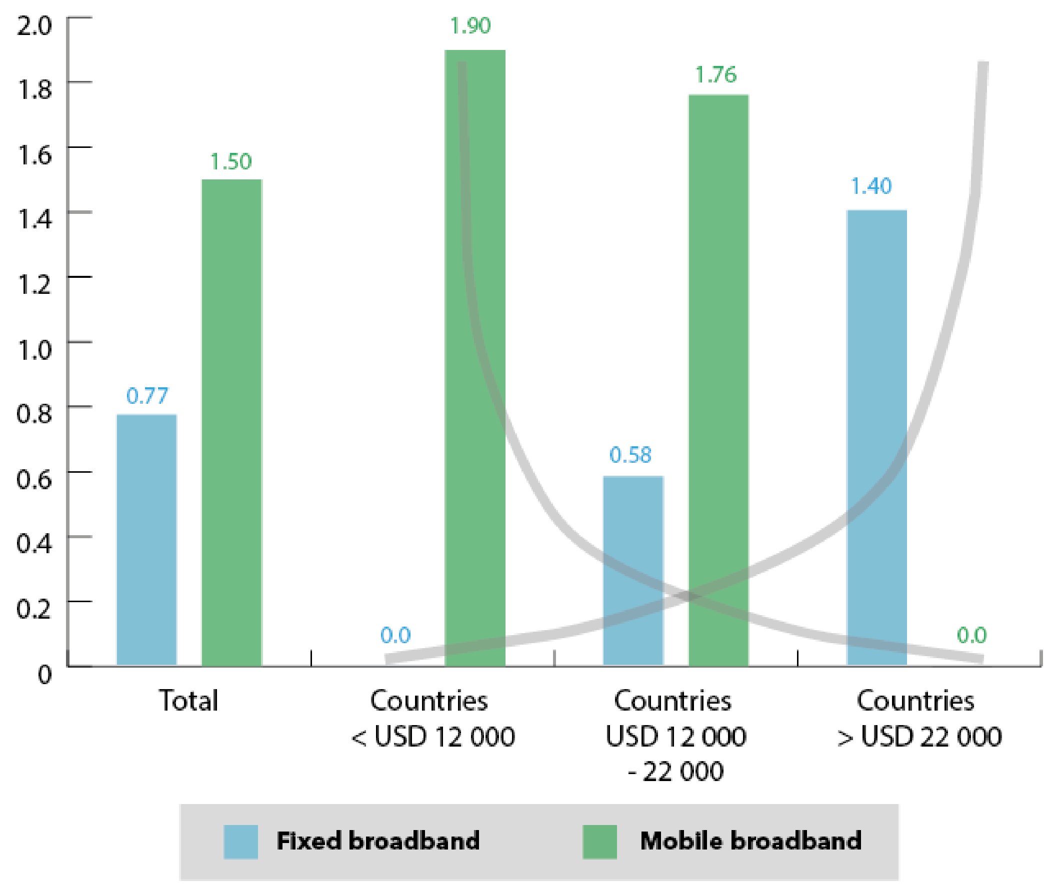
- Europe region countries overall would enjoy an increase of 2.1 per cent. When we include low-income European countries, the increase would be 2.0 – most regional economic impact is concentrated in countries with GDP per capita lower than USD 20 000.

Fixed vs. mobile broadband – economic impact by level of development

Using structural models for the global sample, our analysis of 139 countries confirms the following:

- Fixed broadband (data between 2010 – 2017): its contribution is greater in developed countries, with high penetration of fixed broadband, reflecting the "return to scale" effect.
- Mobile broadband (data from 2010 – 2018): its economic dividend is greater in countries and regions with lower levels of economic development and lower relative mobile penetration reflecting the "diminishing returns" effect. This contribution diminishes in countries and regions with higher levels of penetration and development.

Figure 6: GDP growth impact of an increase in 10% of broadband penetration (in per cent)



Source: ITU publications on the Economic Contribution of Broadband, Digitization and ICT Regulation regional studies

Regional analyses confirm both effects and are summarized in Figure 7 below.

Figure 7: Regional GDP growth impact of an increase in 10% of broadband penetration (in per cent)

	Fixed broadband impact	Mobile broadband impact
Africa	Impact in Africa is as low as that estimated for the global sample of low-income countries – not statistically significant	Impact in Africa is a 2.46% increase – higher than that estimated for low-income countries in the global sample at 1.98%
Asia-Pacific	Overall region: 1.63% and comparable to high-income country global figure of 1.4% because of weight of high-income economies in the region. Zero impact in both low-income groups of countries	Low and medium-income countries enjoy 2.44% increase, higher than overall region's total of 0.51%
Europe	Impact is higher in high-income countries at 2.94% than that of Europe's low-income countries (0.07%, although not significant). Higher too than high-income countries in the global sample (1.4%)	Impact is not significant for high-income countries while low-income countries would enjoy a 2.0% increase – this is statistically significant
Arab States	Impact is 0.71% – higher than the global sample of medium-income countries at 0.58% but lower than high-income countries at 1.40%	Impact is a 1.82% increase – lower than that of low-income countries at 1.90 % but positive and statistically significant relative to high-income countries
Americas	Impact is higher for Americas (United States and Canada) at 1.88% than in Latin America and Caribbean at 1.57%	Impact is a 1.73% increase in Latin America and the Caribbean – higher than in the Americas (United States and Canada) at 1.16%
Commonwealth of Independent States	Impact is 0.63% – somewhat higher than global sample of medium-income countries at 0.58 % but lower than high-income countries at 1.40 %	Impact is a 1.25% increase – which is lower than global sample of low-income countries at 2.0 % but is positive and statistically significant relative to high-income countries

Source: ITU

The economic impact of digitization

What is digitization?

- Digitization is the transformation of the techno-economic environment and socio-institutional operations through digital communications and applications.
- Digitization metrics quantify:
  - The cumulative effect of adoption and usage of multiple information and communication technologies across individual users and enterprises;
  - The development of digital industries;
  - The factors of production of the digital economy;
  - The level of competitive intensity.

An index to measure the development of digital ecosystems: eight pillars, 64 indicators

As the digital ecosystem landscape becomes increasingly complex, we needed to build an index that reflects a wider range of domains and indicators.[11] We have used the Digital Ecosystem Development Index to measure the level of regional digitization, as well as to understand the progress achieved so far and the nature of the challenges ahead.

This Index is a composite metric that quantitatively assesses the eight pillars that make up the digital economy. The Index breaks these down into 64 indicators as set out in the graphics that follow.

[11] The Index for Development of the Digital Ecosystem was developed under funding from CAF Development Bank of Latin America.

Figure 8: Eight elements – the structure of the Digital Ecosystem Development Index

Note: Links are drawn only for relatively strong causal relationships.
Source: CAF

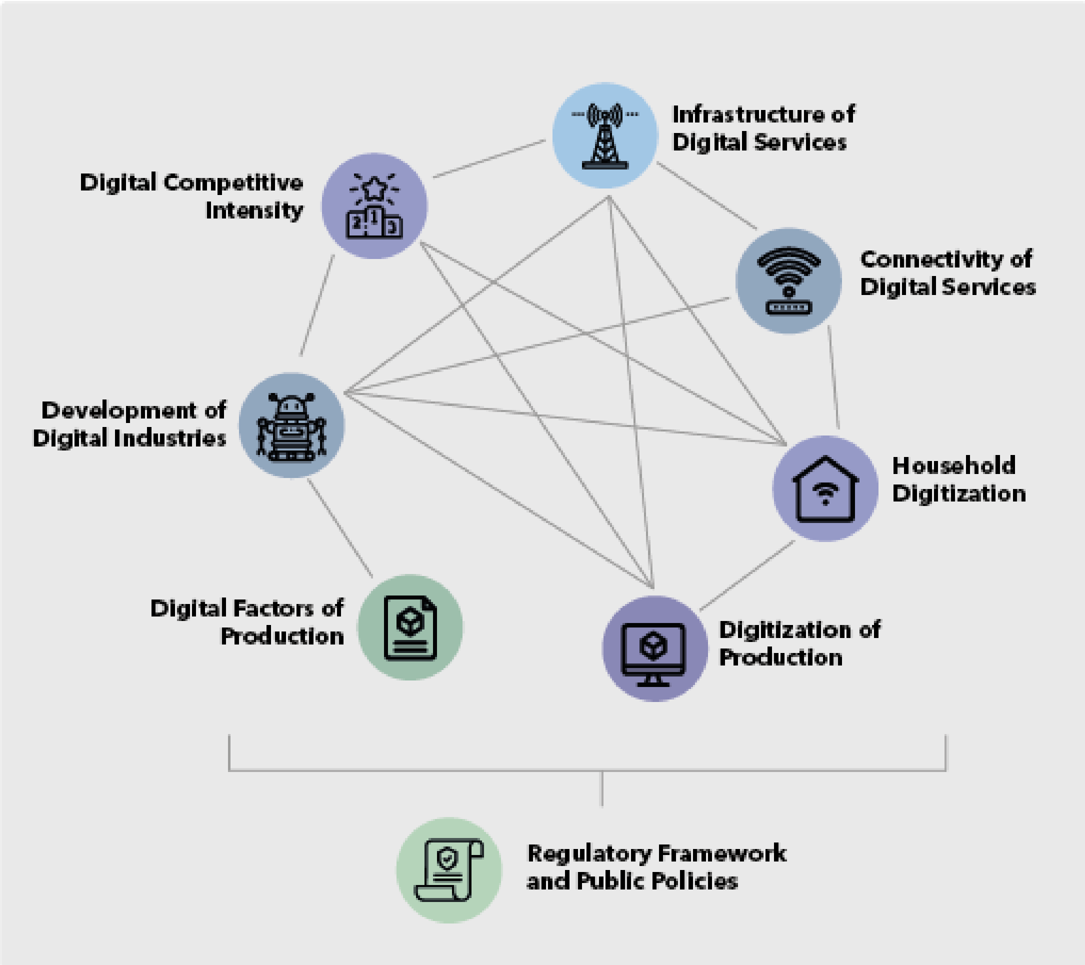
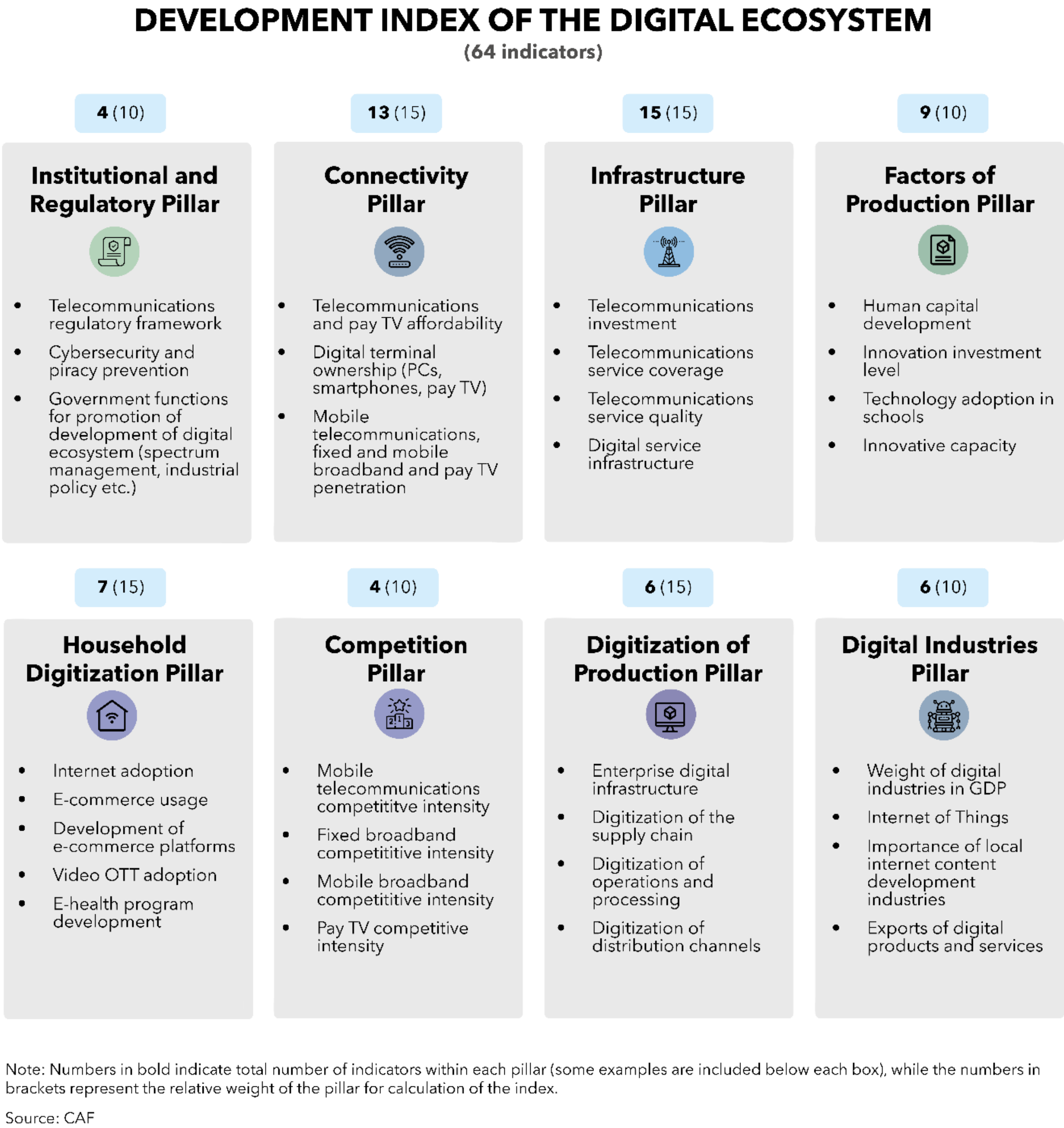


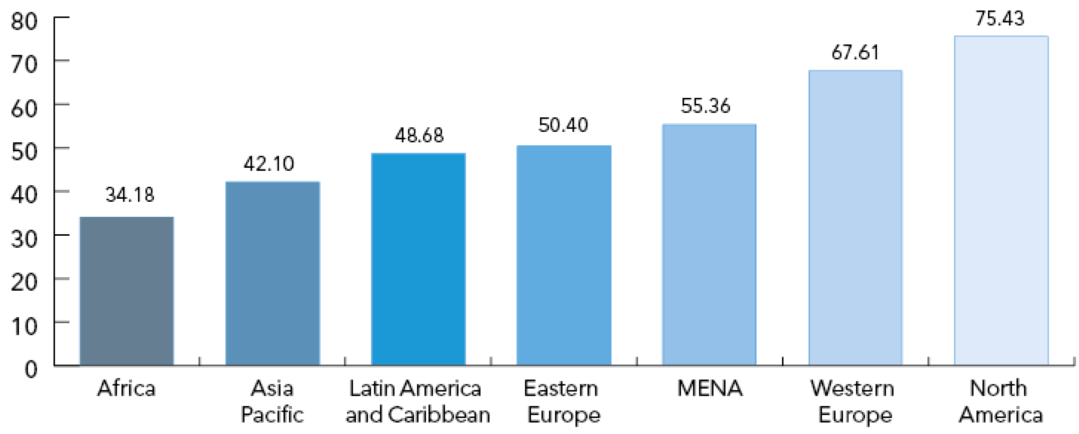
Figure 9: The Index – 64 indicators grouped in eight pillars



Note: Numbers in bold indicate total number of indicators within each pillar (some examples are included below each box), while the numbers in brackets represent the relative weight of the pillar for calculation of the Index.
Source: CAF

As expected, advanced economies depict a higher digitization index (see figure 10)

Figure 10: Comparative development of the digital ecosystem (2018)

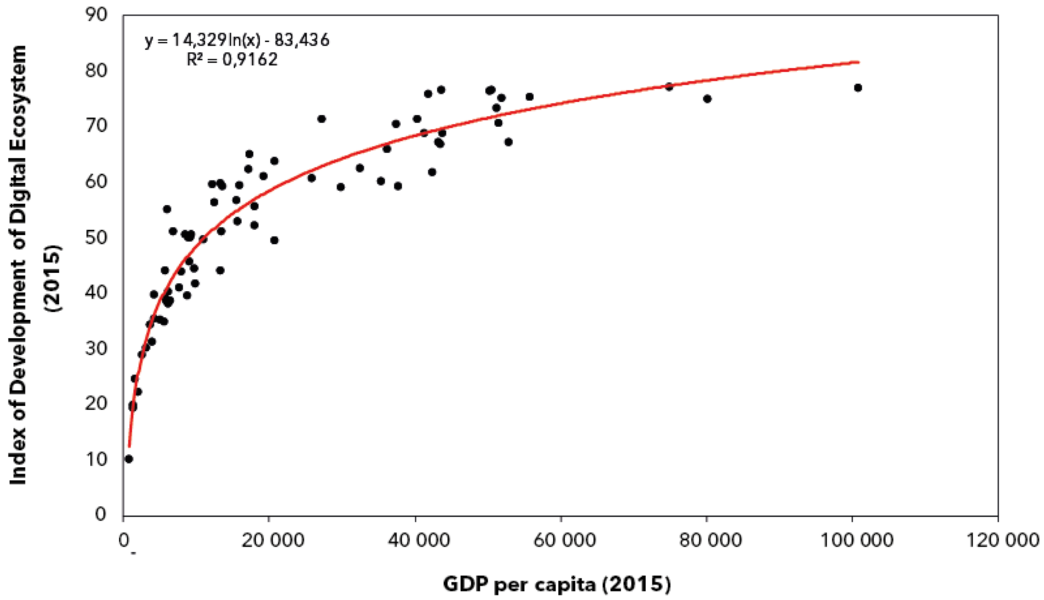


Source: ITU publications on the Economic Contribution of Broadband, Digitization and ICT Regulation regional studies

Digitization correlates with economic development

Digitization is correlated with economic development (see Figure 11 below).

Figure 11: Correlation between GDP per capita and Digital Ecosystem Development Index, 2015



Source: ITU

This study tested three hypotheses in regard to how digitization impacts the economy:

- Its impact is higher than standalone information technologies;
- Impact increases at higher development stages;
- There is a positive impact on productivity.

The econometric models are built on data for 73 countries between 2004 and 2015:

- Africa (4 countries)
- Americas (24 countries)
- Arab States (3 countries)
- Asia Pacific (9 countries)
- Europe (24 countries)
- Commonwealth of Independent States (9)

The endogenous growth model tests the impact on GDP growth and is based on the Cobb-Douglas production function:

$$\text{Log}\ (GDP_{it}) = a_1 \log\ (\text{Fixed capital formation}_{it}) + a_2 \log\ (\text{Labour force}_{it}) + a_3 \log\ (\text{digitization index}_{it}) + a_4 \log\ (\text{previous year GDP})\ \varepsilon_{it}$$

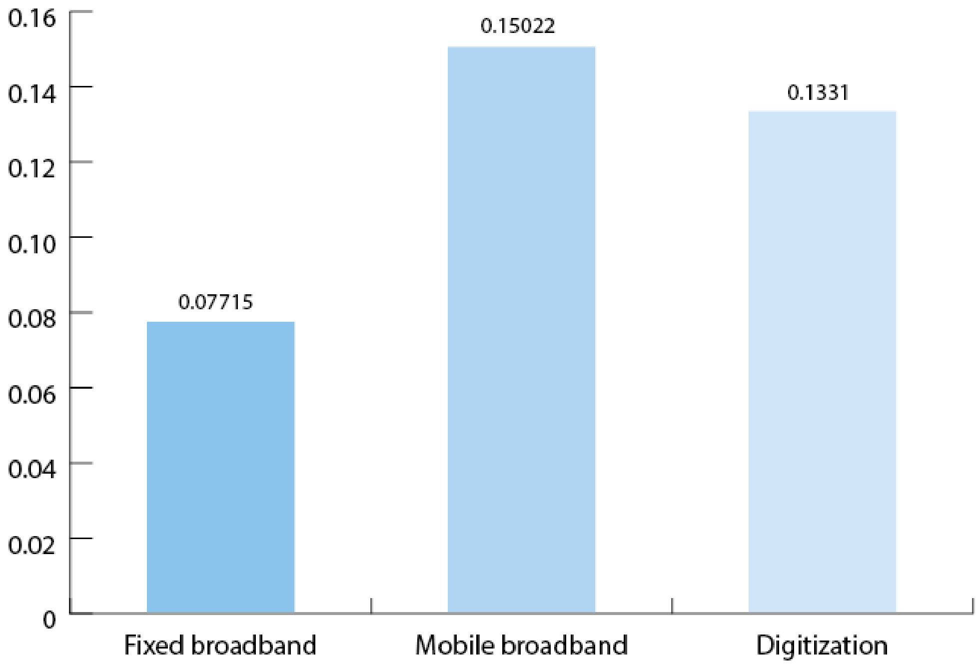
The model to test the impact of digitization on productivity:

$$\text{Log}\ (\text{Productivity}_{it}) = a_1 \log\ (\text{Growth of digitization}_{it}) + a_2 \log\ (\text{digitization index}_{it}) + \varepsilon_{it}$$

Digitization – on par with mobile broadband in boosting economies

On a global scale, digitization has a larger economic contribution than fixed broadband, on a par with that of mobile broadband.

Figure 12: Impact on GDP of 1% increase in independent variable, 2014-2015

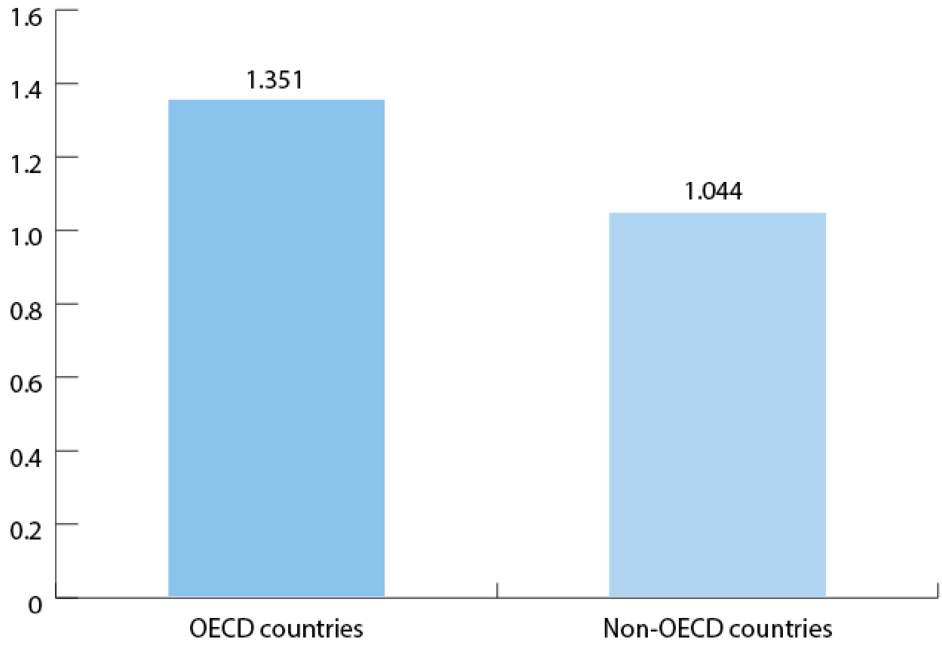


Source: ITU publications on the Economic Contribution of Broadband, Digitization and ICT Regulation regional studies

Digitization boosts advanced economies

The impact of digitization on advanced economies is higher than in emerging countries, confirming the “return to scale” effect (see Figure 13 below).

Figure 13: Impact on GDP of 10% increase in digitization, 2014-2015



Source: ITU

Digitization boosts productivity

Digitization boosts labour productivity – 10 per cent digitization yields an increase of 2.62 per cent. Ten per cent increase yields an increase of 2.28 per cent in total factor productivity.

Policy and regulation drive development of digitization

Institutional and regulatory factors drive the development of digitization in addition to endogenous variables.

We see an acceleration in the digital ecosystem development following changes to policy and institutions that influence deployment and adoption of digital technologies. Note there is a time lag between change and effect.

How did we measure the impact of policy and regulation on digitization? This was based on a multivariate regression model that included two indices as set out below:

Digital Ecosystem Development Index

- Digital infrastructure
- Digital connectivity
- Digitization of households
- Digitization of production
- Digital industries
- Factors of digital production
- Competitive intensity

ITU ICT Regulatory Tracker Index

- Regulatory Authority
- Regulatory Mandate
- Regulatory Regime
- Competition Framework

$$\text{Log (Digital Index}_{it}) = B_1 \text{ Log (Digital Index}_{it-1}) + B_2 \text{ Log (Regulatory Index}_{it-1}) + \text{Year} + \text{Country FE} + \varepsilon_{it}$$

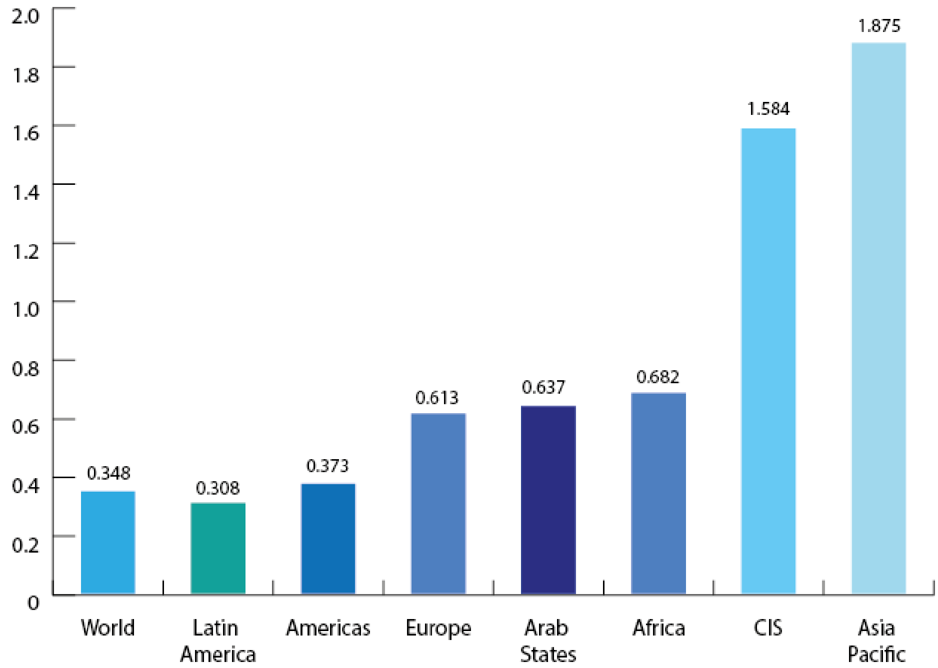
Regional results confirm the importance of regulation and policy

All our regional results confirm the importance of regulation and policy on the development of digitization.

Here we list three mechanisms (that can occur simultaneously) that drive this effect:

- Changes in policy and/or institutions drive increased public ICT investment, which in turn improves network reliability and affordability.
- Institutional change facilitates more effective public policy which in turn can help drive the development of a national digital agenda / a broadband plan / the creation of legislative consensus.
- Sending a signal to the private sector: institutional changes signal to the private sector that ICT and digital development are a cornerstone – in response the private sector (operators and other Internet players) increases investment and commercial aggressiveness. In this way, public initiative functions as a multiplier.

Figure 14: Impact of the 10% of the lagged ITU ICT Regulatory Tracker on the Digital Ecosystem Development Index



Source: ITU publications on the Economic Contribution of Broadband, Digitization and ICT Regulation regional studies

ANNEX A: Review of the related research literature

A review of the research literature on the economic contribution of telecommunications and digital technologies, as well as the impact of the policy variable on the development of telecommunications and digitization has been prepared and published in each of the regional econometric studies.[12] Whenever applicable, the literature was reviewed both in terms of global results and by region in order to ascertain the level of progress of research in each region of the world. The review set the stage for defining the theoretical frameworks that guided this study.

A.1. THE ECONOMIC CONTRIBUTION OF FIXED AND MOBILE BROADBAND

Studies on the economic impact of telecommunications have been produced for the past two decades confirming, to a large extent, that wireline and wireless telephony, as well as fixed and mobile broadband have an impact on economic growth and, in some cases, on employment and productivity (Hardy, 1980; Karner and Onyeji, 2007; Jensen, 2007; Katz *et al*., 2008; Katz, 2011; Katz *et al*., 2009; Katz *et al.*, 2012, Arvin and Pradhan, 2014). Along these lines, a critical issue of the evolving research on network externalities of telecommunications is the impact pattern telecommunications penetration levels may have on output and employment. For example, is there a linear relationship between broadband adoption and economic growth, whereby higher penetration yields larger impact? Or, are we in the presence of more complex non-linear causal effects, such as "increasing returns to scale" and/or "diminishing returns" due to saturation? Along those lines, is it possible to identify a particular effect of increasing returns linked to broadband speed?

The following section summarizes first, the historical evolution of econometric modelling studies of broadband economic contribution. Following this, it examines specific results from studies that have evaluated contribution patterns such as identifying potential returns to scale or diminishing returns effects. More specifically, it focuses on the particular research domain of return to speed. Finally, it examines econometric research conducted within particular geographic regions.

A.1.1. Historical evolution of econometric modelling of broadband economic contribution

Broadband technology is a contributor to economic growth at several levels. First, the deployment of broadband technology across business enterprises improves productivity by facilitating the adoption of more efficient business processes (e.g., marketing, inventory optimization, and streamlining of supply chains). Second, extensive deployment of broadband accelerates innovation by introducing new consumer applications and services (e.g., new forms of commerce and financial intermediation). Third, broadband leads to a more efficient functional deployment of enterprises by maximizing their reach to labor pools, access to raw materials, and consumers (e.g., outsourcing of services, virtual call centers).

Quantitative research aimed at generating statistical evidence regarding the economic impact of broadband is fairly recent. The review of the research indicates that there are multiple approaches to estimate the economic impact of broadband, ranging from highly sophisticated econometric techniques to qualitative micro-level case studies.

A.1.2. The "return to scale" or "critical mass" effect

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[12] The Regional Econometric Studies are available at: https://www.itu.int/en/ITU-D/Regulatory-Market/Pages/Economic-Contribution.aspx.

Research on the causal link between broadband penetration and economic output indicates the existence of a non-linear relationship between the two (following an inverted U shape). At low levels of broadband penetration, the impact of broadband on the economy is minimal because the impact of telecommunications infrastructure on economic output is only maximized once the infrastructure reaches a critical mass point, generally associated with levels of penetration of developed countries.

According to the evidence generated by this body of theory, the impact of telecommunications networks on economic output is maximized once the infrastructure reaches critical mass generally associated with high levels of penetration.

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

A.1.3. The saturation and "diminishing returns" effect

At the other end of the diffusion process, some authors have pointed out a potential "saturation" effect. They have found that, beyond a certain adoption level, the contribution of a telecommunications technology to the economy tends to diminish. For example, Atkinson *et al.* (2009) point out, albeit without quantitative evidence, that network externalities decline with the build out of networks and the maturation of technology over time. There is evidence that supports this argument. It has been demonstrated in diffusion theory that early technology adopters are generally those who can elicit the higher returns of a given innovation. Conversely, network externalities would tend to diminish over time because those effects would not be as strong for late adopters. Along those lines, Gillett *et al.* (2006) argued that the relation between broadband penetration and economic impact should not be linear "because broadband will be adopted (…) first by those who get the greatest benefit (while) late adopters (…) will realize a lesser benefit" (p. 10).

To test the saturation hypothesis, Czernich *et al.* (2009)[13] added dummy variables to account for 10 per cent and 20 per cent broadband penetration to their models explaining broadband contribution to OECD economies. They found that 10 per cent broadband penetration has a significant impact on GDP per capita: between 0.9 and 1.5 percentage points. However, the transition from 10 per cent to 20 per cent yielded non-significant results. This led the authors to postulate that broadband saturation and diminishing returns occurs at the 20 per cent point. Gillett *et al.* (2006), presented above, also included saturation as an independent variable and found that it was negatively related to the increase in economic growth (notwithstanding the possible influence of network effects). In an implicit confirmation of this postulate, Qiang *et al.* (2009) found that economic impact of a 1 per cent increase in broadband is higher in low and middle-income economies and lower in high-income economies.[14] Similarly, in their study of the impact of broadband in Kentucky, Shideler *et al.* (2007) found that economic impact is highest around the mean level of broadband saturation at the county level. Again, this was due to diminishing returns to scale. According to this last study, a critical amount of broadband infrastructure may be needed to sizably increase employment, but once a community is completely built out, additional broadband infrastructure will not further contribute to employment growth. In the case of mobile telephony, Gruber and Koutroumpis (2011) show as well, that mobile telephony's effects on GDP growth correlate with wireless penetration growth up until penetration rates reach 60 per cent, at which point effects tend to subside.

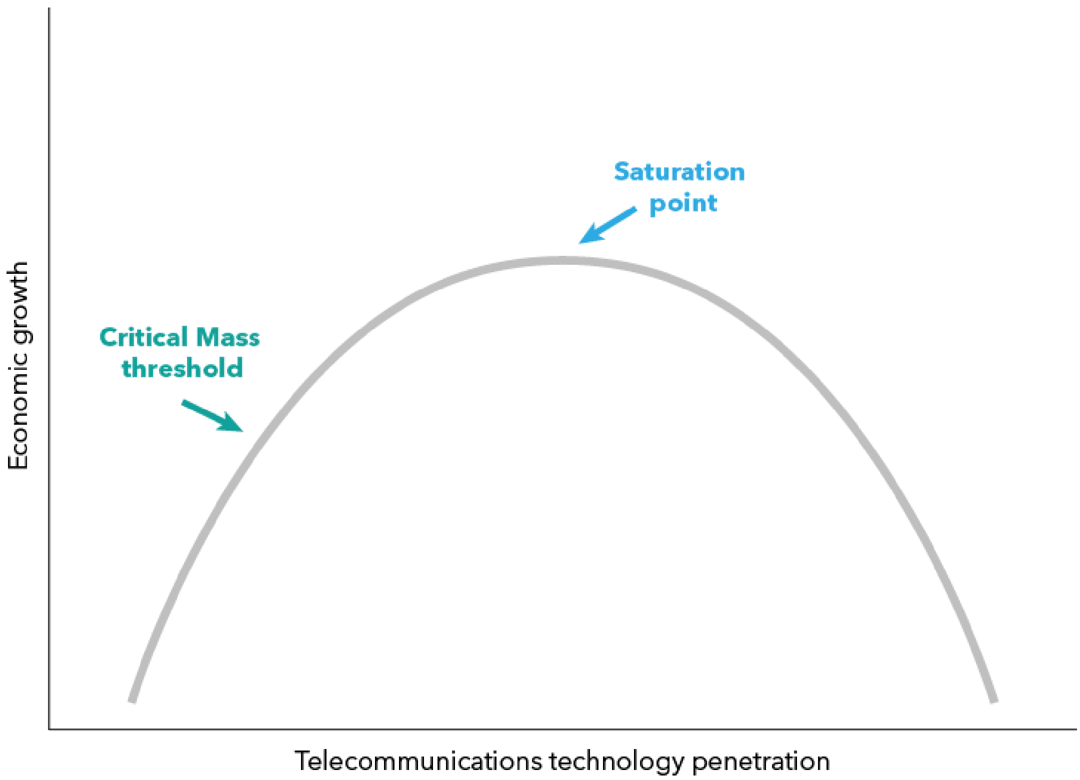
[13] Op. cit. above.

[14] Op. cit. above.

One should be very careful, however, in interpreting the evidence of “diminishing returns”. The saturation evidence still needs to be carefully tested particularly in terms of what is the point beyond which the economic impact tends to diminish. Furthermore, even if there were to be found confirming evidence of saturation with regard to contribution to GDP or employment creation, that would not put into question the need to achieve universal broadband in terms of the other social benefits it yields to end users.

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

Figure A-1. Conceptual framework for the impact of broadband on economic output over the diffusion process



Source: Authors

Figure A-1 shows an inverted U shape of the non-linear relationship between broadband penetration and output. It appears that broadband penetration has only marginal impact until a critical mass of users is achieved. The impact increases beyond the critical mass threshold and until reaching a saturation point – above which the gains in connectivity and access to broadband do not generate additional economic output.

Theoretically, it would appear that there is a non-linear (or inverted U shape) relationship between broadband penetration and output. At low levels of broadband penetration, we believe the impact of broadband on the economy is minimal due to the need to reach "critical mass". According to this theory, the impact of telecommunications infrastructure on the economic output is maximized once the infrastructure reaches a critical mass point generally associated with levels of penetration of industrialized countries. Beyond that point, economic impact tends to slow down, depicting "diminishing returns". As a cautionary point, the literature has evidenced an important dispersion in the level of penetration that would indicate a saturation point when economic impact tends to diminish: it ranges between 20 per cent and 60 per cent.

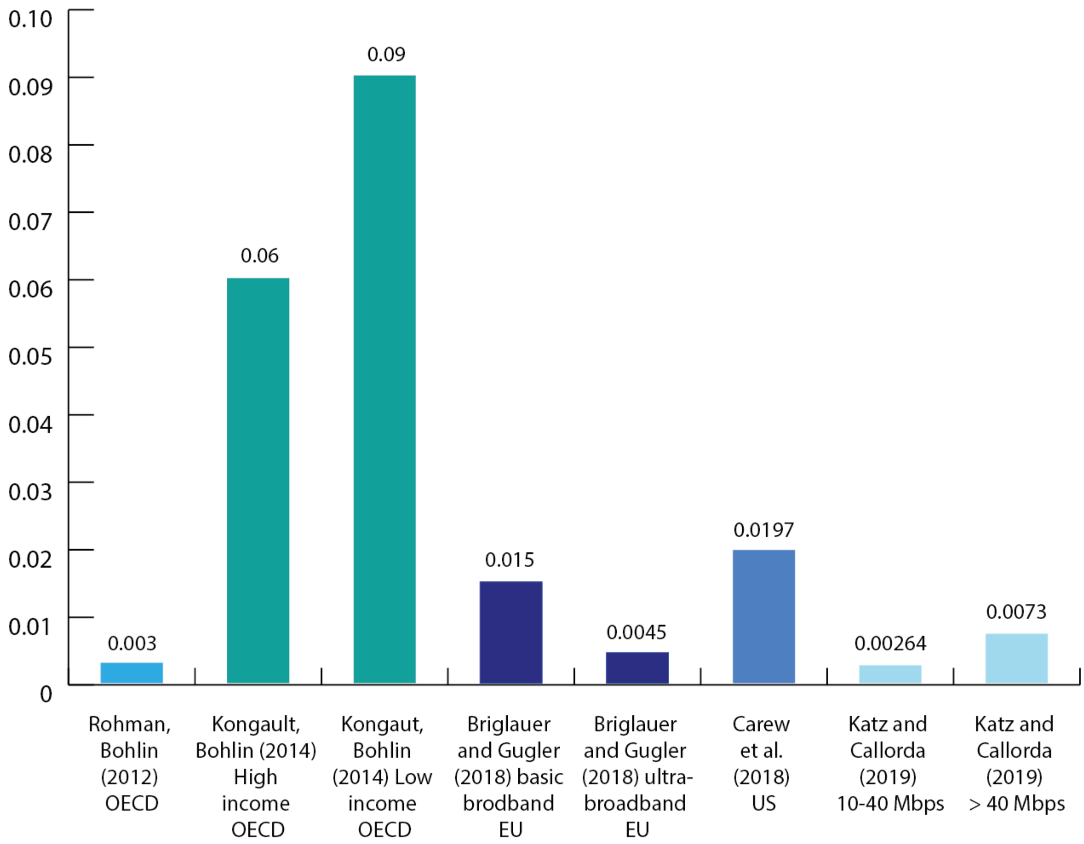
A.1.4. The "return to speed" effect

Beyond research the aggregate economic contribution of broadband, studies have recently started focusing on the so-called "return to speed". Research on the contribution of broadband speed to economic growth generally concludes that faster Internet access has a positive impact on GDP growth. Two types of effects explain this causal relationship. First, faster broadband contributes to an improvement of productivity resulting from the adoption of more efficient business processes. For example, improved marketing of excess inventories and optimization of the supply chain are two of the effects that might be generated. Second, faster connectivity yields an acceleration of the rate of introduction of new products, services, and the launch of innovative business models.

An early study that assessed the impact of broadband speed on GDP (Rohman, Bohlin, 2012) looked at 33 OECD countries and concluded that a 100 per cent increase (or doubling) of speed yields a 0.3 per cent increase in GDP with a sample mean of 8.3 Mbps. Following on this study, Kongaut and Bohlin (2014) used a similar approach, but differentiated between high and low-income OECD countries and determined that an increase in broadband speed of 1 per cent yields an increase in GDP per capita of 0.09 per cent for low income countries and 0.06 per cent for high income countries.

Two studies completed in 2018 provided additional evidence of broadband speed impact on GDP. Briglauer and Gugler (2018) looked at data for 27 EU Member States between 2003 and 2015. In this case, 1 per cent increase in basic broadband adoption was found to increase GDP by about 0.015 per cent, while 1 per cent increase in ultra-fast broadband adoption led to an incremental increase of 0.004-0.005 per cent of GDP. In another iteration, Carew *et al*. (2018) concluded that a 1 per cent increase in speed equates to a 0.0197 per cent in real GDP. Therefore, a doubling of speed (100 per cent increase) yields 1.97 per cent increase in GDP. A recent study by Katz and Callorda (2019) based on an extensive dataset of 159 countries found that the impact on GDP of fixed broadband download speeds under 10 Mbps is non-existent, while once the average speed is in a range between 10 and 40 Mbps, the effect on GDP is positive and statistically significant. The effect on GDP is even greater for download speeds in excess of 40 Mbps. The results of this study (see Figure C-5) are in the range of what was estimated by Briglauer and Gugler (2018) for the EU ultrabroadband impact, while the difference with Carew *et al*. (2018) is likely because, since broadband adoption is not included as independent variable for control purposes, the effect of speed subsumes broadband penetration.

Graphic A-2. Studies measuring the GDP impact on Broadband Speeds (impact of 1% increase in speed on GDP) (%)



Source: Compiled by the authors

As indicated in Graphic A-2, while all studies conclude that broadband speed has an impact on GDP, the range of contribution varies. Some of the difference is explained by methodologies used. For example, Carew *et al*. (2018) did not include broadband adoption as an independent variable which means that the effect of speed subsumes broadband penetration. In other cases, the difference can be explained by the timing of the data used.

Can a saturation effect attached to broadband penetration and GDP be extended to broadband speed? Koutroumpis (2018) argues that a country that has reached the saturation point in speed may experience additional GDP growth although this would not be attributed to the network anymore but to new products and services enabled by the network.

A.1.4.1. Broadband speed and household income

While broadband speed has been consistently found to have a positive effect on economic growth, the evidence of a positive contribution of Internet speed to household income is less conclusive. Rhoman and Bohlin (2013) concluded that there are positive benefits from broadband speed on income, though they are not linear and continuous, but nonlinear and stepwise. Furthermore, the authors found that the impact for lower speed is greater in BRIC countries and for higher speeds it is greater in OECD countries. On the other hand, Ford (2018) analysed data of US and found no economic payoff from a 15 Mbps speed difference.

A.1.4.2. Broadband speed and enterprise productivity

The contribution of broadband speed to enterprise productivity has been studied in terms of its efficiency enhancement and productivity levels. In a study of Irish firms, Haller *et al.* (2019) found significant productivity gains from broadband availability in two services sectors: information and communication services and administrative and support service activities. The effects measured for these two sectors were large, equivalent to about a third of the typical variation in productivity. Smaller effects were found in other sectors. These results suggest the benefits of broadband for productivity depend heavily upon sectoral and firm characteristics rather than representing a homogeneous effect. Cariolle *et al.* (2018) study firms in 62 countries, using World Bank data, and detected a large impact of broadband speed on a firm's average annual sales and sales per worker.

A.1.4.3. Broadband speed and job creation

Research on the impact of broadband speed on employment, which takes place through the contribution to firm relocation and start-up incubation, is fairly conclusive. With the exception of one study, all research has been focused on the United States. Whitacre *et al.* (2014) looked at local level data of non-metropolitan United States counties between 2001 and 2010 and identified a positive impact of broadband speed on unemployment reduction. In particular, rural areas with fast broadband tend to attract more creative class workers. Bai (2016) studied United States counties between 2011 and 2014 and found that while broadband has a positive impact on employment, ultra-fast broadband has less incremental effects. Lobo *et al*. (2019) studied the counties within the US state of Tennessee and found that unemployment rates are about 0.26 percentage points lower in counties with high speed broadband compared to counties with low speed service. Coinciding with Whitacre *et al*. (2014), this study found that better quality broadband has a disproportionately greater effect in rural areas.

The only study conducted outside the United States was done by Hasbi (2017), analysing panel data on 36 000 municipalities in France between 2010 and 2015, the author found that deployment of high-speed broadband (> 30 Mbps) increases company relocation and start-up development in those areas in the non-agricultural sector. These two effects yield a positive contribution to reduction of unemployment.

A.1.4.4. Broadband speed and consumer surplus

Consumer surplus is defined as the amount that consumers benefit from purchasing a product for a price that is less than what they would be willing to pay. Broadband consumer surplus, typically assessed against dial up or pricing differences, indicates a high willingness to pay for speed. Most studies of consumer surplus derived from faster speed are based on surveys or focus groups where consumers stipulate the amount they would be willing to pay for a service such as broadband (Savage *et al.* (2004); Greenstein and McDewitt (2011); Liu *et al*. (2018)).

Finally, other studies on consumer surplus focus the assessment of how consumers react to variations in price according to their data usage.

A.2. REGIONAL STUDIES OF THE ECONOMIC IMPACT OF BROADBAND

While some of the research reviewed above focused on specific geographies, it was pertinent to reevaluate it in light of progress that has occurred in each region of the world to ascertain what has taken place in terms of econometric modelling at the regional level. As mentioned above, the full description of this research is available on each regional econometric study.

A.3. THE ECONOMIC IMPACT OF DIGITIZATION

The study of a country or region stage of development in the adoption of Information and Communication Technologies has been progressing over the last twenty years. While the original focus was to assess the deployment and adoption of telecommunications 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.).

This new perspective has led to the emergence of the concept of digitization. This chapter focuses first on providing a definition of digitization. Given that this phenomenon is comprised of multiple technology trends, its measurement requires the development of composite indices. The efforts in this domain are being reviewed in the second section. Once measurement of digitization was established, the estimation of its economic impact was conducted.

A.3.1. What is digitization?

Digitization *per se*, is the process of converting analogue information to a digital format. Digitization, as a social process, refers to the transformation of the techno-economic environment and socio-institutional operations through digital communications and applications.[15] 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 composite metrics that allow us to determine a country's level of digital eco-system development.

Digitization metrics aim to quantify the cumulative effect of adoption and usage of information and communication technologies. While most of the research literature measuring the social and economic impact of ICT focuses on discrete technology platforms, the holistic adoption and usage of information technology results in enhanced effects that go beyond the contribution of specific platforms. Furthermore, to achieve a significant impact, digitization has to be widely adopted in the economic and social fabric of a given country. As such, they have to be widely utilized by individuals, economic enterprises and societies, embedded in processes of delivery of goods and services (e.g. eCommerce), and relied upon to deliver public services (e.g. eHealth, eGovernment).

A.3.2. Measurement of digitization

The study of a country or region stage of development in the adoption of Information and Communication Technologies has been progressing over the last twenty years. While the original focus was to assess the deployment and adoption of telecommunications 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

[15] See Katz and Koutroumpis, 2013a.

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 Telecommunications Union's *ICT Development Index*, the World Bank's *Knowledge Economy Index*, the World Economic Forum *Network Readiness Index*, and the Inter-American Development Bank's *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.

The first index of digitization developed[16] was based on six components (see Table A-3).

Table A-3. Structure of Original Digitization Index

Components	Subcomponents	Sub-Subcomponents
Affordability	Residential fixed line cost adjusted for GDP per capita	Residential fixed line tariff adjusted for GDP per capita
		Residential fixed line connection fee adjusted for GDP per capita
	Mobile cellular cost adjusted for GDP per capita	Mobile cellular prepaid tariff adjusted for GDP/capita
		Mobile cellular prepaid connection fee adjusted for GDP per capita
	Fixed broadband Internet access cost adjusted for GDP per capita	
Infrastructure Reliability	Investment per telecom subscriber (mobile, broadband and fixed)	Mobile investment per telecom subscriber
		Broadband investment per telecom subscriber
		Fixed line investment per telecom subscriber
Network Access	Network Penetration	Fixed Broadband penetration
		Mobile Phone penetration
	Coverage, Infrastructure and Investment	Mobile cellular network coverage
		PC population penetration
		3G Penetration
Capacity	International Internet bandwidth (kbps/user)	
	% Broadband connections higher than 2 Mbps	
Usage	Internet retail volume	
	E-government usage	
	% Individuals using the internet	
	Data as % of wireless ARPU	
	Dominant Social Network Unique Visitors per month Per Capita	
	SMS Usage	
Human Capital	% Engineers in labour force	
	% Skilled labour	

Source: Katz and Koutroumpis, 2013a

The increasing complexity of the digital eco-system required constructing an index that reflected a larger number of domains and indicators. The index for measuring the development of a digital ecosystem, constructed with support of CAF Development Bank for Latin America,[17] is a composite metric for quantitatively assessing the eight pillars comprising the digital economy.

According to this conceptual structure, the digital ecosystem is defined as a set of interconnected components (or pillars) operating within a socio-economic context. For example, the 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

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[16] Katz and Koutroumpis, 2013a; Katz *et al*., 2013b, Katz *et al*., 2014.

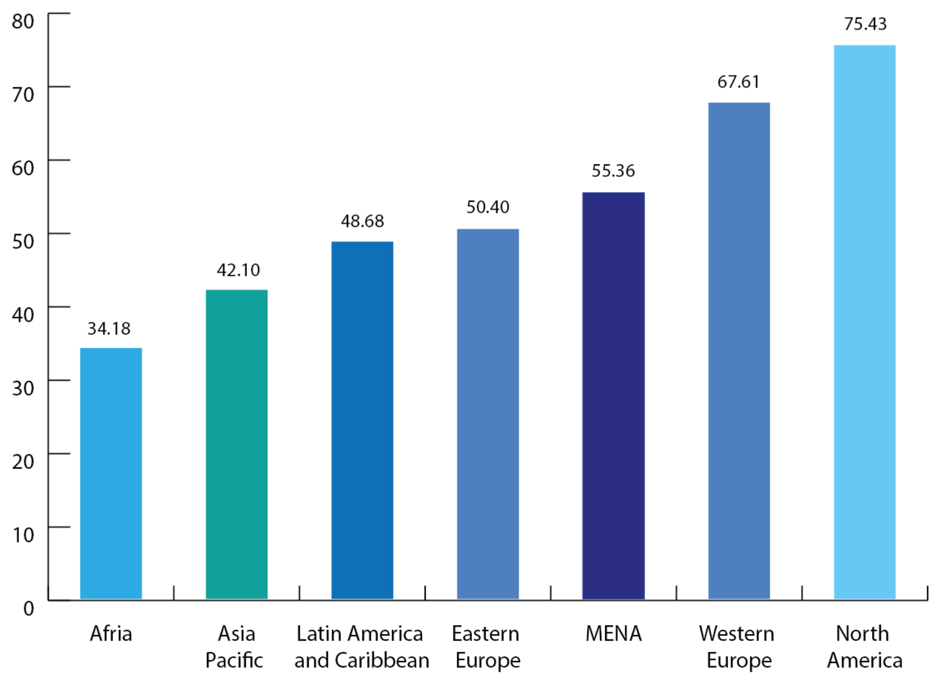
[17] Katz and Callorda, 2018.

proposition to users. 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, telecommunications 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 for digital industries to operate within the 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.

Given that the digital ecosystem embodies a complex interaction among its eight components, the measurement of its development requires the creation of an index composed of eight pillars, each of which is a composite sub-index based on multiple indicators. In total, the Digital Ecosystem Development Index is based on 64 indicators (see image relating to the measurement of digitization conducted by an index composed of 64 indicators grouped in eight pillars, and shown above in Figure 9).

This index has been used to measure the development of regions of the world (see Graphic A-5), as well to understand the progress achieved so far and the nature of the challenges facing ahead.

Graphic A-5. Comparative Development of the Digital Ecosystem (2018)



Note: Countries included in each region are those with GDP per capita higher than USD 5 000 and a population of 5,000,000 or more, which include Australia, China, South Korea, India, Japan, Malaysia, New Zealand, Singapore, and Thailand for Asia Pacific, Canada and United States for North America, Cote d'Ivoire, Egypt, Kenya and South Africa for Africa, Azerbaijan, Belarus, Bulgaria, Czech Republic, Estonia, Hungary, Kazakhstan, Latvia, Poland, Romania, Russian Federation, Slovakia, Slovenia, and Turkey for Eastern Europe, Austria, Belgium, Denmark, Finland, Germany, Greece, Iceland, Ireland, Italy, Luxemburg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom for Western Europe, Israel, Lebanon Saudi Arabia and United Arab Emirates for Middle East and North Africa, and Argentina, Barbados, Bolivia, Brazil, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Guatemala, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, Trinidad & Tobago, Uruguay, and Venezuela for Latin America and the Caribbean.

Source: Authors

The Index facilitates the estimation of digitization economic impact.

A.3.3. Economic impact of digitization

The original index, discussed above, was used to test the impact of digitization on economic growth. For this purpose, we used an endogenous growth model that links Gross Domestic Product to the Fixed Stock of Capital, Labor 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 were estimated through an econometric model.

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

The Digitization Index was found to have a positive and significant effect at the 5 per cent level indicating a strong effect on economic output. A ten-point increase in the Digitization Index had approximately a 3 per cent impact on GDP for the period 2004-2010 resulting on an annualized effect of 0.50 per cent.[18][19]

The Digital Ecosystem Development Index was run for 73 countries for the period 2004-2015, which resulted in 803 observations, and included fixed effects by country (Katz and Callorda, 2018). According to the model, an increase of 1 per cent in the Digital Ecosystem Development Index results in a 0.13 per cent growth in GDP per capita. This means, for example, that an increase in the Digital Ecosystem Development Index from 50 to 51 will yield an increase of per capita GDP of 0.26 per cent (accounting both for direct and indirect effects on output).

The model was also run for OECD and non-OECD countries to test for a "return to scale" effect. The results indicate that the impact of the digital ecosystem on more advanced economies is higher than emerging countries. Thus, an increase of 1 per cent in the Digital Ecosystem Development Index yields an increase of 0.14 per cent in per capita GDP for OECD countries, while the impact of a

[18] This was used as a base case of an "average" country whose Digitization Index increased by 10 points.
[19] Annual Growth Rate (CAGR) attributed to digitization derives from formula (1):

$$CAGR = \left[\left(\frac{\frac{Digitization_{2010}}{100-Digitization_{2010}} - \frac{Digitization_{2004}}{100-Digitization_{2004}}}{\frac{Digitization_{2010}}{100-Digitization_{2010}}}\right) * \hat{a}_3 + 1\right]^{1/6}$$

similar change in non-OECD countries will be 0.10 per cent. In other words, the higher the economic development, the stronger the contribution of the digital ecosystem on economic growth.

A.4. THE IMPACT OF POLICY ON DIGITIZATION

While very limited research has been conducted so far in terms of measuring the impact of policy on the development of digitization, substantial work has been done regarding the impact of public policies on the development of specific technologies. The policy variables that affect digitization and ICT sector performance have multiple dimensions, ranging from the regulatory to the institutional ones, both being either specific or not to the sector. In general terms, variables can be grouped in three categories: 1) the institutional framework, 2) the regulatory framework, and 3) non-sector specific policies which can have a spillover effect on the ICT sector.

The institutional framework variables comprise the factors such as the type of governmental entities that are in charge of developing digital policy or regulating the ICT sector and the providers of service. For example, the variables included in this cluster comprise the overall policy environment (e.g. existence of Cabinet-level position centralizing all digital policy matters (telecommunications, content, computing), the scope and scale of a telecommunications national regulatory authority, its enforcement powers, and independence, the existence of an overarching ICT national planning process, and the scope of government participation in the digital sector.

The regulatory framework cluster comprises all the variables related to specific policies and regulatory approaches. They include market entry regulation (e.g. vertical separation, local loop unbundling, rights of way, numbering scheme, spectrum management), price regulation (interconnection, mobile termination rates, weighted average cost of capital, retail pricing), investment incentive regulation (e.g. asymmetry), the regulatory process (e.g. market analysis ex-ante), and the application of regulation (e.g. technological neutrality, operational conditions, compliance monitoring).

Finally, non-sector specific policies that can have an impact on the performance of the sector comprise variables such as direct foreign investment restrictions affecting market entry and capital structure, other trade restrictions affecting services supply, proactive long term government planning, and regulation of audiovisual content affecting convergence (e.g. restrictions of telecommunications carriers regarding content distribution). In particular, policies that promote and facilitate the adoption of ICT by late adopters (socio-economic disenfranchised and small and medium enterprises), such as digital literacy programmes and equipment subsidization, play an extremely important role in fostering the emergence of a high-performance sector.

ANNEX B: Countries analysed for economic impact of fixed and mobile broadband

- Argentina
- Australia
- Austria
- Azerbaijan
- Barbados
- Belarus
- Belgium
- Bolivia
- Brazil
- Bulgaria
- Canada
- Chile
- China
- Colombia
- Costa Rica
- Côte d'Ivoire
- Cuba
- Czech Republic
- Denmark
- Dominican Rep.
- Ecuador
- Egypt
- El Salvador
- Estonia
- Finland
- France
- Germany
- Greece
- Guatemala
- Haiti
- Honduras
- Hong Kong, China
- Hungary
- Iceland
- India
- Ireland
- Israel
- Italy
- Jamaica
- Japan
- Kazakhstan
- Kenya
- Korea (Rep.)
- Latvia
- Lebanon
- Luxembourg
- Malaysia
- Mexico
- Netherlands
- New Zealand
- Nicaragua
- Norway
- Panama
- Paraguay
- Peru
- Poland
- Portugal
- Romania
- Russian Federation
- Saudi Arabia
- Singapore
- Slovakia
- Slovenia
- South Africa
- Spain
- Sweden
- Switzerland
- Thailand
- Trinidad & Tobago
- Turkey
- United Arab Emirates
- United Kingdom
- United States
- Uruguay
- Venezuela

ANNEX C: Data sources for models testing the economic impact of fixed and mobile broadband

Indicator	Source
GDP per Capita (PPP)	IMF
Fixed Broadband Subscriber Penetration	ITU - OVUM
Capital - Gross Capital Formation (% of GDP)	World Bank
Education- School Enrolment, tertiary (% gross)	World Bank
Fixed Telephone Subscribers	ITU
Rural Population (% of total population)	World Bank
Fixed Broadband Price	ITU
HHI Fixed Broadband	OVUM
Fixed Broadband Revenue	ITU - OVUM
Mobile Broadband Unique Subscribers Penetration	GSMA
Mobile Unique Subscribers Penetration	GSMA
Mobile Broadband Price//ARPU	ITU - GSMA
HHI Mobile Broadband	GSMA
Mobile Broadband Revenue	GSMA

ANNEX D: 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 (Mbps)	Akamai
Infrastructure	Quality of service	Average mobile broadband download speed (Average Mbps)	Akamai
Infrastructure	Quality of service	Fixed broadband connections with download speed higher than 4 Mbps (percentage)	Akamai
Infrastructure	Quality of service	Fixed broadband connections with download speed higher than 10 Mbps (percentage)	Akamai
Infrastructure	Quality of service	Fixed broadband connections with download speed higher than 15 Mbps (percentage)	Akamai
Infrastructure	Quality of service	Fibre optic 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
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;

Pillar	Sub-pillar	Indicator	Source
			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	UN
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; Eurostats
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; Eurostats
Digitization of production	Digital distribution	Per cent enterprises that sell products over the Internet	UNCTADstat; TAS; Eurostats
Digitization of production	Digital processing	Per cent workforce using the Internet	UNCTADstat; TAS; Eurostats
Digitization of production	Digital processing	Per cent workforce using computers	UNCTADstat; TAS; Eurostats
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 agencies
Competitive intensity	Competition level	HHI mobile telephony	GSMA; Regulatory agencies
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

Pillar	Sub-pillar	Indicator	Source
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	IoT	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 enrollment (per cent population)	World Bank; UNESCO
Factors of digital production	Schools	Per cent educational establishments with Internet access	UNESCO; CEPAL
Factors of digital production	Schools	Computers per students ratio	UNESCO; CEPAL
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
Institutional and regulatory	Cybersecurity and piracy	Per cent of non-licensed installed software	BSA, The Software Alliance
Institutional and regulatory	Cybersecurity 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 Bank

ANNEX E: Econometric methodology

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.[20] 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:

- In the production function, GDP is linked to the fixed stock of capital, labour and the mobile infrastructure proxied by mobile penetration.
- 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.
- 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 specified for two cross-sectional samples of countries. This methodology would allow the three hypotheses explained above to be tested while controlling for endogeneity effects.[21]

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

[21] 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).

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.

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 20 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 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

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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."

value proposition to users.[22] **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.

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 CAF 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 CAF 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

[22] Telecommunications services provide value insofar that they allow consumer access to the Internet.

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 CAF Digital Ecosystem Development Index. For this purpose, two models were developed initially: the first tests the correlation between the ICT Regulatory Tracker and the CAF Digital Ecosystem Development Index. The underlying premise is that higher regulatory performance is directly related to the development of the digital economy:

$$Dig.Index_{it} = {}_{\beta 1}Reg.Index_{it} + \text{Year F.E.} + \text{Country F.E.} + e_{it}$$

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

$$Dig.Index_{it} = {}_{\beta 1}Reg.Index_{it} + {}_{\beta 2}Reg.Index_{it-1} + \text{Year F.E.} + \text{Country F.E.} + e_{it}$$

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

$$\text{In } (Dig.Index_{it}) = {}_{\beta 1}\text{In } (Dig.Index_{it}) + {}_{\beta 2}\text{In } (Dig.Index_{it-1}) + \text{Year F.E.} + \text{Country F.E.} + e_{it}$$

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 CAF 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 CAF Digital Ecosystem Development Index.
ICT Regulatory Tracker and CAF Digital Ecosystem Development Index pillars

TABLE: Colored with white lines

ICT Regulatory Tracker	ICT Regulatory Tracker (w/o Competition component)	Regulatory authority component	Regulatory mandate component	Regulatory regime component	Competition framework		
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

Acronyms

AI	Artificial Intelligence
AR	Augmented Reality
APRU	Average Revenue Per User
BDT	Telecommunication Development Bureau
BRIC	Brazil, Russia, India and China (ITU)
CAF	Corporación Andina de Fomento
CEPAL	Commission économique pour l'Amérique latine et les Caraïbes
CIS	Commonwealth of Independent States
FTTH	Fibre to the Home
FTTx	Fibre to the x
GDP	Gross Domestic Product
HHI	Herfindahl Hirschman Index
ICT	Information and Communication Technology
IMF	International Monetary Fund
IoT	Internet of Things
ITU	International Telecommunication Union
M2M	Machine-to-Machine
OECD	Organisation for Economic Co-operation and Development
OTT	Over The Top
PPP	Public-Private Partnership
R&D	Research and Development
RME	Regulatory and Market Environment Division
SMS	Short Message Service
USPTO	United States Patent and Trademark Office
UNCTAD	United Nations Conference on Trade and Development
UNESCO	United Nations Educational, Scientific and Cultural Organization
VR	Virtual Reality
WHO	World Health Organization

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