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The impact of policies, regulation, and institutions on ICT sector performance

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This report has been prepared for the International Telecommunication Union (ITU) led by the ITU Telecommunication Development Bureau (BDT) Regulatory and Market Environment Division (RME) and the ITU Regional Office for Asia and the Pacific.

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Executive summary

This study uses econometric modelling to examine the impact of the regulatory and institutional frameworks on the performance of the ICT (Information Communication Technologies) sector and its contribution to the national economy as a whole. Its purpose is to provide policy-makers and regulators with the empirical evidence required to further regulatory reform in the ICT sector and address the challenges and gaps in current regulatory frameworks for digital services and applications. The study scope explores a set of critical questions:

- What is the impact of government policies and regulation on the performance of the ICT sector, as measured by capital investment, network deployment, service pricing, consumer demand, and ultimately impact on the economy?
- Is competition enough of an incentive to drive an improvement of sector performance?
- How long does it take for changes in regulation and policies to affect sector performance?

The modelling is built on data from 145 countries between 2008 and 2019 – an up-to-date global data set, comprising 50 initiatives of policy reforms and institutional characteristics as well as 13 indicators of ICT sector performance.

Upgrading regulatory frameworks – what matters?

The evidence provided by the study points to major findings that are of great importance in informing governments, policy-makers, regulators and operators as they formulate general infrastructure and telecommunication investment decisions in the years ahead:

- The regulatory institutional framework, which is composed of regulatory authority, regulatory mandate, regulatory regime, and competition model, is linked to a positive and significant increase in telecommunication investment. This entails having a separate, independent and autonomous ICT regulator with a wide scope in its attributes, adopting the best regulatory practices (encompassing the licence regime, service quality monitoring, spectrum sharing, etc.), and promoting a competitive environment.
- A reduction in taxation is associated with a significant boost in capital investment, as it increases available financial resources for network deployment.
- A reduction of government bureaucratic processes is linked to a significant increase of capital investment, confirming the relevance of public efficiency. This highlights the importance of reducing the required time for obtaining permits related to network deployment (for instance, through the adoption of "silence procedures[1]"), addressing municipal network construction requirements (by promoting a centralized norm of national scope), and reducing other red-tape costs.
- Being affiliated to international organizations that promote sound regulations and good practices to enhance a business-prone environment through a binding commitment for reforms (namely, Organisation for Economic Co-operation and Development (OECD) or World Trade Organization (WTO)) is linked to higher telecommunication investment.

[1] Similar to the international law concept, this would allow an operator requesting an infrastructure deployment permit to tacitly receive approval if no response occurs from the local authorities within a certain time.

Regulatory power boost for mobile

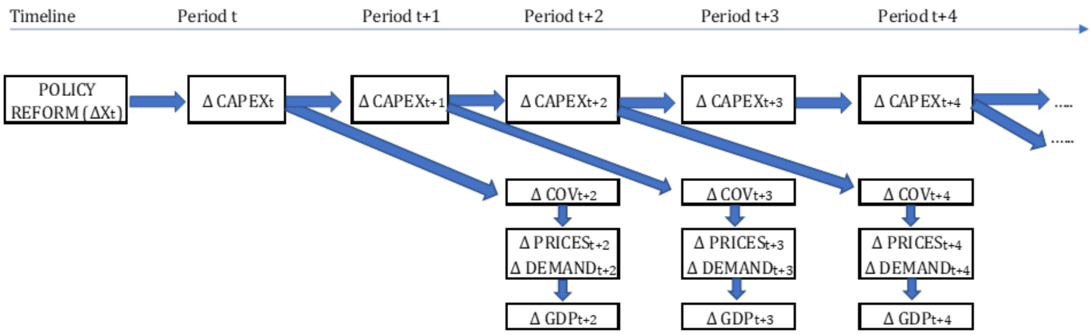
Specifically, for the mobile sector, the following policies were found to have a positive and significant impact on investment, yielding in turn service coverage gains, price reductions, higher adoption levels and consequently, a macroeconomic impact in terms of GDP per capita:

- The introduction of a national broadband plan (combined with a strong implementation framework and leadership), suggesting that the formulation of a digital agenda is crucial to accelerate innovation and boost investment.
- A convergent licensing framework, as it provides a flexible approach to ICT policies, more adapted to technological advances, maximizes the return of infrastructure investment.
- Allowing voluntary spectrum sharing agreements, thereby helping operators to maximize the opportunities to make investments profitable, represents an incentive for network deployment.
- The introduction of mobile number portability, that removes barriers and renders the market more dynamic, stimulates competition and innovation.
- Openness to foreign operators, increases access to capital for network development and modernization, and allows for the transfer of technology and know-how.
- The existence of a national competition authority contributes to monitoring multiple market segments in order to avoid anticompetitive actions.

On the other hand, other policy variables did not show a significant impact on investment. That is the case, for instance, of infrastructure sharing obligations, spectrum band migration allowance, or permission for spectrum secondary trading.

All in all, these findings suggest that positive market signals and flexible approaches are necessary conditions for telecommunication operators to thrive and maximize network deployment, benefitting consumers and the society as a whole. Given the dynamic nature of the empirical model, the positive impact from policy and institutional reforms will translate into further gains beyond a single time period, as capital spending in future years will continue to grow as a result of the increase in its own past values. This economic flow of performance gains can be summarized as follows (Figure A).

Figure A: Dynamic economic gains after a policy reform in period t



Source: ITU

Accordingly, the positive impact in terms of GDP per capita will take place two years after the initiative is enacted and continue to yield a contribution through several time periods.

The empirical evidence generated in this study is expected to provide useful inputs to policy-makers in terms of a deeper understanding of the linkages between the regulatory and institutional context and ICT market outcomes, and on the characteristics that effective public policies should have. However, some caveats need to be made regarding the study results. Some of the indicators are limited in terms of their full predictability. For example, the binary nature of some of the initiatives (i.e., existence of a broadband plan yes/no) does not provide an indication of their intrinsic quality. On another note, the pandemic of COVID-19 is expected to have an incidence in the presented results. On the one hand, the GDP contraction experienced worldwide is affecting telecommunication revenues, negatively impacting capital spending levels. On the other hand, the lockdown period is resulting in an enhanced use of digital technologies, thus representing an unobservable shock increasing adoption levels. These effects will be econometrically measurable when 2020 data becomes available.

With these caveats, the results are powerful in terms of informing policy decisions. Regulators and policy-makers alike should assess the quality of the institutional framework guiding industry operations and examine whether some of the policies found to be critical in promoting an improvement of performance are in place. Even if they have been adopted, it is important to examine the policies in detail to determine how much they meet some of the international best practices.

Table A: At a glance headlines from the report

ITU ICT Regulatory Tracker comprised of all four scores	An increase of 10% in the Tracker score is associated with an increase of fixed and mobile investment of over 7%.
Regulatory authority (independence, accountability, and enforcement power) score	An increase of 10% in the score is associated with an increase of close to 8% in fixed and mobile investment.
Regulatory mandate (responsible for QoS, licensing, interconnection rates, spectrum, universal service, broadcasting, Internet, IT and consumer issues) score	An increase of 10% in the score is associated with an increase of close to 11% in fixed and mobile investment.
Regulatory regime (good practices in terms of licensing, interconnection, QoS, infrastructure sharing, access regulation, and number portability, among others) score	An increase of 10% in the score is associated with an increase of approximately 4% in fixed and mobile investment.
Competition framework (competitive intensity in fixed, mobile, and broadband services, among others) score	An increase of 10% in the score is associated with an increase of close to 7% in fixed and mobile investment.
Profit tax (non-sector specific)	A 50% reduction in profit tax affecting the business sector is associated with an increase of fixed and mobile investment of nearly 14%.
Bureaucratic burden	A 50% reduction in administrative time required for doing business is linked to an increase in fixed and mobile investment of 17%.
OECD membership	OECD membership is associated with an increase in 36% in fixed and mobile investment.
Five-year WTO membership	Countries with a five-year membership of WTO are associated with a 17.5% more fixed and mobile investment with respect to non-members.

Table A: At a glance headlines from the report (continued)

Development of a national broadband plan	The development of a national broadband plan increases mobile investment by 15%, network coverage by 14%, price reduction by 8%, and mobile penetration by close to 3% after two years.
Convergent 'technology neutral' licences	Moving from service and network specific to convergent licensing is associated with an increase of mobile investment of 10%, network coverage by over 9%, price reduction by over 5%, and mobile penetration by approximately 2% after two years.
Spectrum sharing agreements	The possibility of performing voluntary spectrum sharing agreements is associated with a 18% increase in mobile investment, network coverage by over 17%, price reduction by close to 10%, and mobile penetration by over 3% after two years.
Mobile number portability	The introduction of mobile portability has a positive effect of increasing mobile investment by close to 11%, network coverage by 11%, price reduction by approximately 6%, and mobile penetration by 2% after two years.
ICT sector opened to foreign investment	When the market is opened to foreign players, capital investment is stimulated, increasing by 14%, network coverage by over 13%, price reduction by close to 8%, and mobile penetration by close to 3% after two years.
National competition authority (non-sector specific)	The existence of a competition authority (non-sector specific) is related to an increase in almost 10% in mobile investments, network coverage by close to 9%, price reduction by over 5%, and mobile penetration by close to 2% after two years.
Optimal industry concentration level	Optimal mobile industry concentration level (that is to say, the one that maximizes capital investment) was found to be close to HHI=4113.

1. Introduction

The impact of regulation, public policy, and institutions on the performance of the telecommunication/ICT sector has been a key topic concerning operators, policy-makers and academia. While the economic impact of ICT has been studied for over many decades yielding a solid understanding of the sector externalities[1], the effect of ICT policies and regulation on sector performance has been less conclusive. Yet, this issue remains front and centre of the concerns of all sector stakeholders. Along these lines, many questions have not been fully addressed so far. For example:

- What are the sector and non-sector specific policies that have an impact on service affordability and coverage?
- Which sector and non-sector specific policies maximize capital expenditures (CAPEX) and therefore, sector innovation?
- What is the contribution of institutional factors, such as regulatory quality or membership of international organizations, to policy success?
- How much time does it take for a particular policy to yield an impact on the sector performance?

While research has focused on addressing some of these questions in the past, studies have typically focused on a particular causal link or have narrowed down the question to explore causality under a number of constraints. In fact, the review of research conducted as a starting point of this study indicates that the questions above have not been tackled in a holistic manner. Part of the reason has been the lack of data on the measurement of policy and institutional variables. Fortunately, work conducted by the International Telecommunication Union (ITU) in the past years has generated an extensive data set measuring sector policy features covering not only developed but also developing countries.[2]

To fill this gap in the evidence, the purpose of this study is to develop a set of quantitative analyses measuring the impact of the regulatory and institutional frameworks on the performance of the telecommunication/ICT sector and on the national economy as a whole. The study provides empirical evidence of the causal relationships between policy and sector outcomes. In particular, it focused on understanding how government policies and regulations affect market outcomes, such as prices, innovation and access to digital services. In addition, the study assesses the subsequent effect of telecommunication sector performance on the economy, recognizing that the impact of service adoption on the economy has been extensively covered in a prior study (Katz and Callorda, 2020).

The study's ultimate purpose is to provide ICT policy-makers and regulators with the empirical evidence required to promote further regulatory reforms in the ICT sector and address the challenges and gaps in current regulatory frameworks for digital services. These issues have become extremely critical under the current circumstances. A recent report of an economic expert roundtable organized by ITU concluded that, considering the effect of COVID-19, policy and regulatory frameworks may need to be adjusted to stimulate investment whilst maintaining a 'sensible' level of competition shifting from a 'purist' to a 'pragmatic' viewpoint on State aid

[1] See literature and evidence reviewed in Katz, R. and Callorda, F. (2020). *How broadband, digitization and ICT regulation impact the global economy*. Geneva: International Telecommunication Union retrieved at: http://handle.itu.int/11.1002/pub/816ff1af-en.

[2] See ITU ICT Regulatory Tracker, retrieved at: https://www.itu.int/go/tracker.

regulations[3]. All in all, the roundtable concluded that ICT regulation post COVID-19 cannot rely only on the lessons from the past and needs to re-examine some of its fundamental premises.

2. Model to assess the impact of the policy context on market outcomes

2.1. Research review[4]

The research exploring the causal framework of telecommunication/ICT sector regulation and policies has largely focused on the impact of competition, performing analyses from different perspectives, such as its incidence on service adoption, pricing and innovation:

- *Competition and service adoption*. Research assessing the impact of competition on service adoption focused initially on the effects of privatization on sector performance. Once the wave of privatizations was largely completed, the main focus shifted towards industry liberalization and service adoption. Finally, the third body of research focuses implicitly on the transitive relationship between specific policies, such as network unbundling, and service adoption.
- *Competition and pricing*. Another body of research focused on the relationship between competition and service prices. Similarly, some have analysed the impact of wireless mergers on prices.
- *Competition and innovation*. The most important body of research on the relationship between competition and innovation focuses on the impact on capital investment, which leads in turn to network deployment and, consequently, innovation. An important area of research has indicated that the effect of competition and innovation may not be linear but shaped by an 'inverted-U'.

Another relevant research topic has been the impact of taxation. Taxation has also been found to have an impact on service adoption and on innovation:

- *Sector specific taxation and service adoption*. Studies in the field have intended to provide answers to some relevant questions, such as: *What is the appropriate level of taxation?* And, *which services should be taxed?* A reduction of taxes on telecommunication services and devices may have a positive impact on service adoption as a result of demand elasticities.
- *Sector specific taxation and innovation*. Taxation on telecommunication operators can have an important impact on investment. A decrease in taxation affecting equipment purchases increases investment, generating in turn positive effects in terms of GDP growth.

Another body of the research literature has focused on the key role that effective spectrum management plays in the delivery of quality and affordable services to the consumers:

- *Spectrum management and service adoption*. Effective spectrum management can have an important impact on market outcome, and as a result, on adoption levels and consumer surplus. Spectrum management is central to the quality and affordability of mobile broadband services.
- *Spectrum management and innovation*. To encourage substantial investment and innovation in mobile services, it is important to have a transparent, long-term plan including a strategy for making sufficient amounts of spectrum available. Spectrum management,

3 International Telecommunication Union (2020). *The economic impact of COVID-19 on digital infrastructure*. Geneva: ITU, retrieved at: https://www.itu.int/pub/D-PREF-EF.COV_ECO_IMPACT.

4 A detailed literature review covering all the above-mentioned areas is presented in Appendix A.

its pricing, and the imposition of associated obligations can have a significant impact on investment and innovation.

Beyond specific policies, sector outcome is expected to be influenced by the ICT institutional framework, as well as other macro policies and contextual factors:

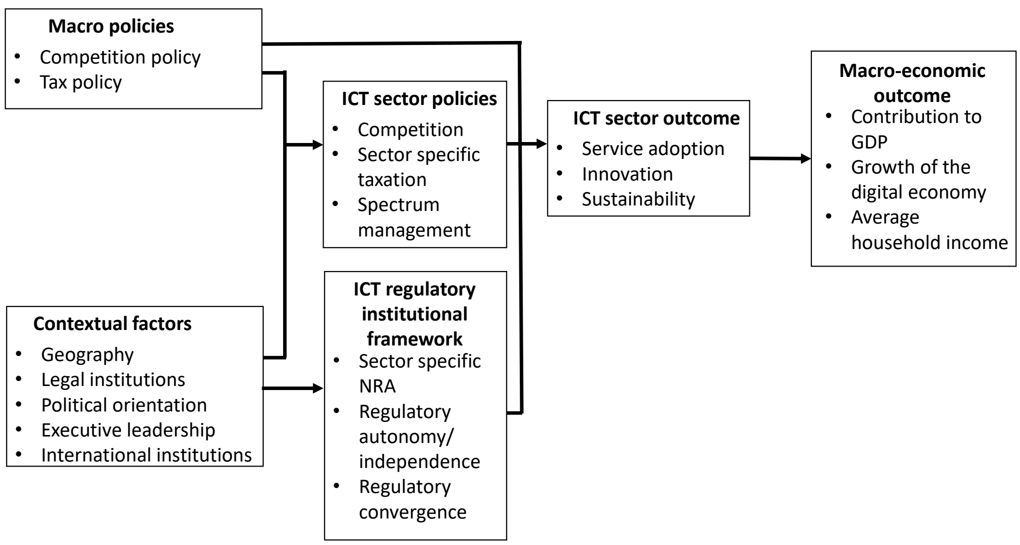
- Through its monitoring and enforcement capability, the ICT regulatory institutional framework intermediates the causality between policies and market outcomes. The research literature has provided vast evidence regarding the impact of the institutional framework on adoption and sector performance.
- In addition, some of the regulations reviewed above are not necessarily specific to the ICT sector but are influenced by macro policies. A typical example is that of competition, which in the telecommunication sector should be understood within the context of general competition law.
- Finally, sectoral policies and the design of its institutional framework are not formulated in a vacuum. They are influenced by a number of contextual factors, such as international organization affiliations, executive leadership, or institutional efficiency.

While research has focused on addressing some of these questions related to the impact of regulation and policy on sector performance, most studies tend to focus on a particular causal link or narrow down the question to explore causality under a number of constraints. Along those lines, the purpose of this study is to attempt to integrate many of the variables studied before within a comprehensive causal framework.

2.2. A causal model to frame the impact of policy and institutional factors on ICT sector performance

As suggested in the literature, a range of causal links take place between the policy and regulatory context and market outcomes in the telecommunication/ICT sector. The combination of all the elements within a single causality framework is presented in the flow diagram in Figure 1.

Figure 1: Overall model by considering causality flows



Source: ITU

The economic model for this study explores the interplay between multiple variables:

- The principal causal relationship between ICT sector policies and market outcomes is predicated on multiple links whereby each of the three independent variables (competition model, sector specific taxation, spectrum management) affect each of the three dependent variables (service adoption, innovation, and sector sustainability).
- In turn, the impact of ICT sector policies on market outcomes is mediated by the ICT regulatory institutional framework, which conditions policy effectiveness.
- Furthermore, the development of ICT sector policies is influenced by non-sector specific macro policies (such as national competition policy models and tax policy) and contextual factors (such as the country's position in the policy diffusion process, legal institutions, and the role of influencing parties).
- Downstream, the ICT market outcome has an impact on the macro-economic outcome in terms of growth of the GDP, growth of the digital economy and other economic variables such as average household income.

This causal model is not static. As some of the research indicates, independent variables may interact among themselves to drive different effects (such is the case of the competition model and spectrum management practices). In addition, some of the outcome variables might also condition each other creating 'second order' effects. For example, the rate of innovation impacts service adoption.

In order test this set of causal links, a structural model was developed consisting in four main empirical equations, described as follows:

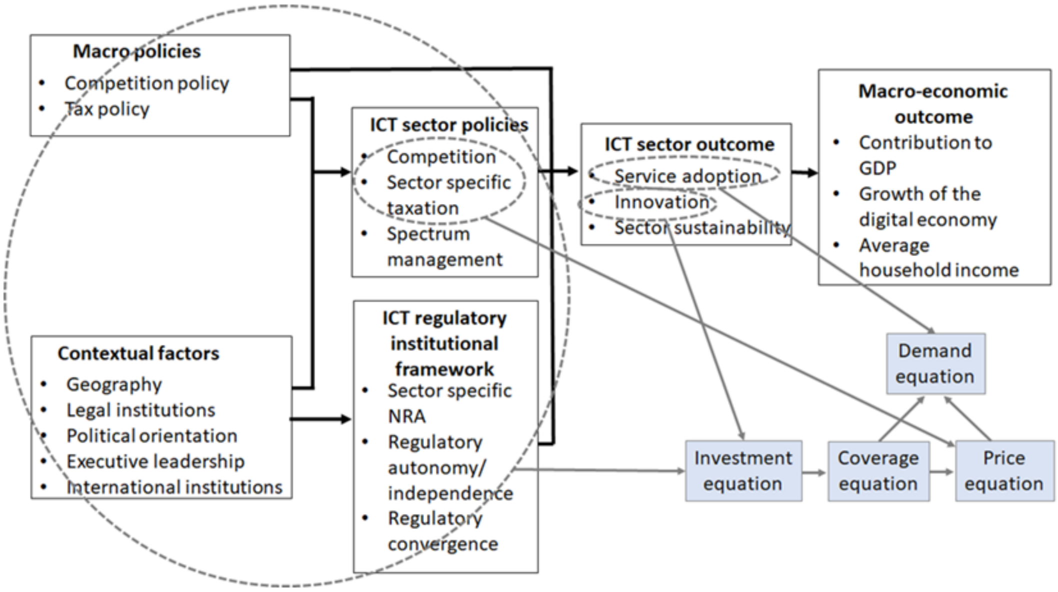
Table 1: Econometric model equations

Investment equation[5]
$\log\left(CAPEX_t\right)=\alpha+\beta\log\left(CAPEX_{t-1}\right)+\gamma\log\left(REVENUE_{t-1}\right)+\delta\left(X_t\right)+\varepsilon_1$
Coverage equation
$\log\left(COVERAGE\right)_t=\Upsilon+\Phi\log(CAPEX_{t-i})+\sum_{i=1}^{i=3}v_i\log\left(COVERAGE_{t-i}\right)+\lambda\log(URBAN)_t+\varepsilon_2$
Price equation
$\log\left(PRICES\right)_t=\Lambda+\pi(TAX_t)+\psi\log(COVERAGE_t)+\Gamma(COMPETITION_t)+\varepsilon_3$
Demand equation
$\log\left(DEMAND\right)_t=\Theta+\eta\log(PRICE_t)+\tau\log(COVERAGE_t)+\varsigma\log\left(GDPpc_{t-1}\right)+\sigma\left(AGE_t\right)+\varepsilon_4$

The term *X* in the investment equation denotes a vector of variables linked to the policy context. Accordingly, policy context variables are expected to directly impact investment, and indirectly (with a time-lag) contribute to service coverage, prices and demand. Figure 2 places the equations reported in Table 1 in the context of the overall causality model presented above:

5 The CAPEX variable is considered in the aggregate rather than normalizing it on a per capita basis; however, since it is also included as a lagged independent variable and the consideration of aggregate revenues controls for any scale effect.

Figure 2: Model equations in the context of the overall causality flows



Source: ITU

In order to test the model a data set was built from the available information sources and an empirical strategy was specified following the specialized econometric literature:

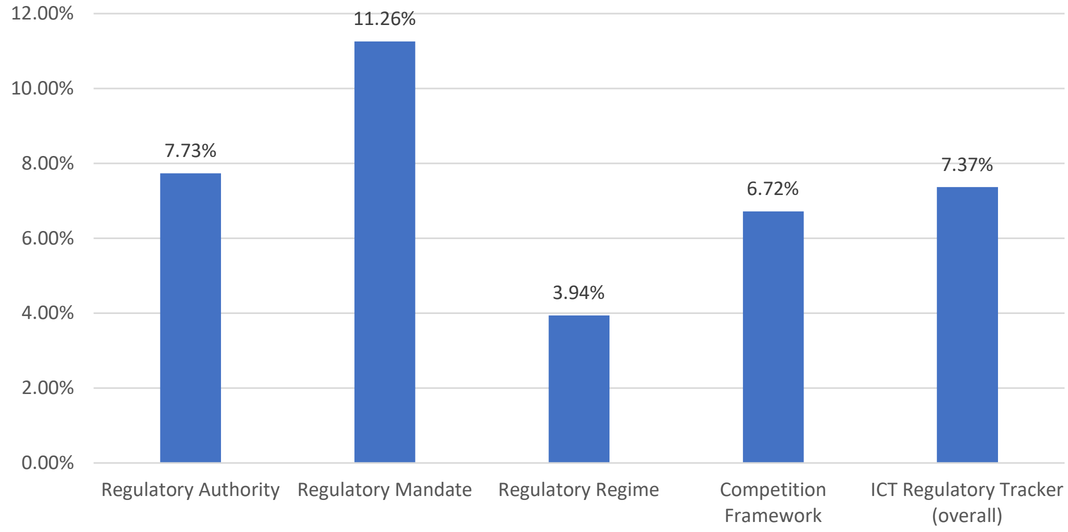
- The database is composed by 145 countries during the period 2008-2019 (country list presented in the Appendix B and the complete details of the variables in Appendix C).
- The investment equation of the model was estimated first for the combined fixed and mobile telecommunication sector, and, following that, for the mobile segment (voice and broadband) specifically. The remaining equations were estimated only for mobile, due to limited fixed broadband data availability.
- The econometric specification was designed intending to maximize its robustness by controlling for all possible sources of endogeneity. The complete methodology utilized is described in detail in Appendix D.

3. Key drivers of fixed and mobile telecommunication investment

The first analysis was focused on testing the impact of key regulatory and policy variables on investment (defined as the aggregate capital spending of fixed and mobile operators in a given year). This was done by introducing as contextual variables the respective ICT regulatory pillars indices and the overall score of the ITU ICT Regulatory Tracker[6] (see Figure 3).

[6] See Table C.1 in Appendix C for the complete description of the ITU ICT Regulatory Tracker variables.

Figure 3: Impact on telecommunication capital investment after an increase of 10% in the respective sub-index (contemporaneous effect)



Source: ITU
Notes: The impact measures an increase of 10% (over the mean) in the respective indices Simulations performed with the coefficients reported in Table E.1 in Appendix E.

The econometric estimate of the investment equation for the overall telecommunication sector confirms the relevance of the policy and institutional context for network deployment[7]

- A 10 per cent increase in the regulatory authority pillar score is associated with an increase in investment of almost 8 per cent. This means that having a separate ICT regulatory agency, with the desired characteristics (in terms of independence, accountability, and enforcement power), contributes to creating a suitable framework that spurs investment.[8] A review of pillar scores indicates that most countries have made important advances in this field. In 2019, 85 per cent of all covered countries achieved a score above the mean (10), while 42 per cent achieved a score of at least 18 (of a total of 20).
- A 10 per cent increase in the regulatory mandate pillar score is linked to an increase in investment of 11 per cent. This suggests the relevance of the scope of attributions attributed to the regulatory agency (in terms of being in charge of Quality of Service (QoS), licensing, interconnection rates and price regulation, radio spectrum, universal service, broadcasting, Internet, IT and consumer issues). Having a separate ICT regulator rather than a government ministry in charge of a wide array of regulatory topics contributes to improving the environment required to spur investments. Most countries have experienced important advances in this area, with 91 per cent exhibiting a value above the mean (11) in 2019, and 50 per cent reaching a value of 18 or higher (of a total of 22).
- A 10 per cent increase in the regulatory regime pillar score is associated with almost 4 per cent increase in investment. This pillar refers to the adoption of good practices related to specific regulations in terms of licensing[9], interconnection, QoS infrastructure sharing, access regulation, and number portability, among others. This points out at the relevance

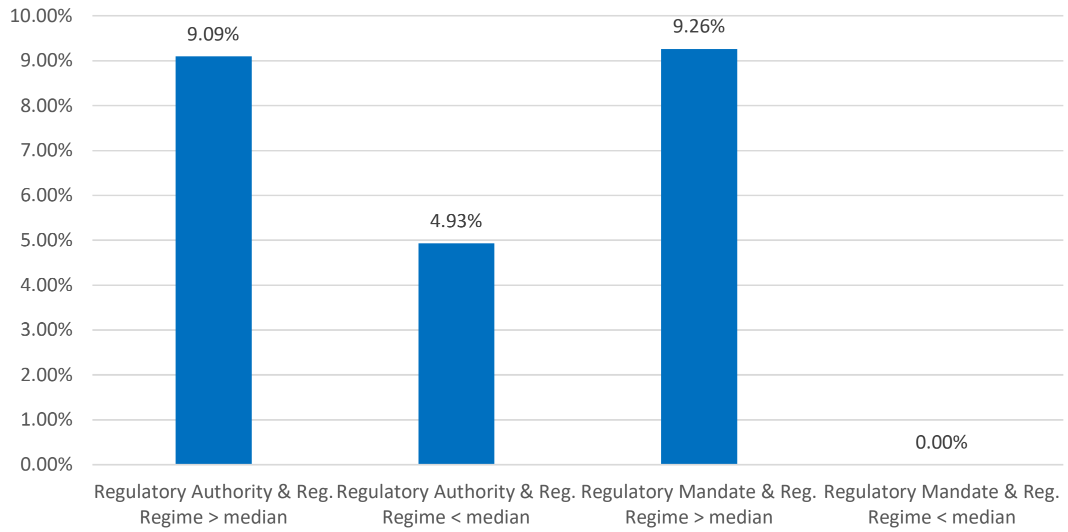
[7] The complete econometric results are presented in Table E.1 in Appendix E. In addition, no major differences were found for these estimated results between developing and developed countries (see detailed results in Table E.2 in Appendix E).
[8] This is consistent with the findings of the surveyed literature such as Wallsten (2001), Gutierrez (2003), Maiorano *et al.* (2007), Waverman *et al.* (2007), among others.
[9] The indicators in this pillar consider if only service-specific, multi-service individual, unified/global licences, general authorizations or simple notification are provided, or if there is a licence exemption.

of adopting best regulatory practices to accelerate investment. Almost 75 per cent of the surveyed countries reached in 2019 a score above the mean of 15, and 50 per cent reached a score of 20 or higher (of a total of 30).

- A 10 per cent increase in the competition framework pillar score, is linked to an increase of almost 7 per cent in investment.[10] This score measures competitive intensity in local and long distance, mobile, and broadband services, among others, the criteria for determining dominance or significant market power (SMP), plus the allowance of foreign presence in the ICT sector. 50 per cent of the surveyed countries reached in 2019 a score above 23, while 30 per cent reached a score above 26 (of a total of 28).

The regulatory characteristics measured through the ICT Regulatory Tracker pillars are very much complementary among themselves. The results in Figure 4 indicate the cumulative impact of regulatory authority and regulatory mandate pillars according to two specific sub-samples, depending on the values taken by the regulatory regime pillar score (above or below the overall sample median). As can be observed, the measured impact of regulatory authority is reduced by 50 per cent for countries that lack a propitious regulatory regime, while on the other hand, regulatory mandate is no longer significant for this country group. In other words: the relevance of the regulatory authority and regulatory mandate to explain investment levels is largely diminished when not accompanied by sound policies.

Figure 4: Impact on telecommunication capital investment after an increase of 10% in complementary drivers (contemporaneous effect)



Source: ITU
Note: The impact measures an increase of 10% (over the mean) in the respective indices.
Simulations performed with the coefficients reported in Table E.1 in Appendix E.

Overall, these results are consistent with Katz (2020), who analysed the impact of ICT Regulatory Tracker indices on the Digitization Index, finding that regulatory and institutional maturity in the ICT arena make indeed a significant difference in driving the growth of digitization[11].

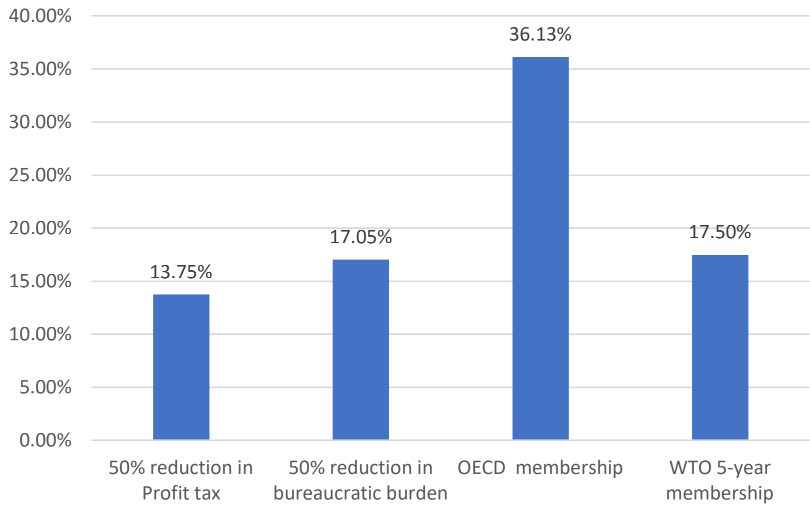
[10] This result supports previous findings in the literature regarding the relevance of a suitable competition environment to enhance telecommunication development (Wallsten, 2001; Li *et al*, 2004; Grzybowski, 2008).

[11] ITU Report *How broadband, digitization and ICT regulation impact the global economy*, available at www.itu.int/en/ITU-D/Regulatory-Market/Pages/Economic-Contribution.aspx

Another analysis addresses the impact of the complete ITU ICT Regulatory Tracker score, which is composed by all four previous pillars. An increase of 10 per cent in the Tracker score is associated with an increase of investment of over 7 per cent, thereby indicating the significant importance of regulation in driving performance of the ICT sector. The advance made by most countries is reflected by the fact that 50 per cent of the sample has achieved a score of at least 75 (of a total of 100) in 2019. However, there are important differences according to the level of development: while the sample of developing countries reach an average score of 67, the mean for developed economies is 87. Considering that developing countries lag the level of telecommunication investment, the results indicate that if an average developing country increases the Tracker score by 20 (that is to say, reaches a score similar to that of a developed nation), that would yield a 24 per cent increase in investment.

Beyond the ICT Regulatory Tracker variables, other drivers of investment as considered in the causality model presented in Figure 1, were tested (see Figure 5).[12]

Figure 5: Simulations of variables impact on telecommunication capital investment (contemporaneous effect)



Source: ITU
Note: Simulations performed with the coefficients reported in Table E.3 in Appendix E.

- A 50 per cent reduction in profit tax affecting the business sector is associated with an increase of ICT investment of nearly 14 per cent. This means that, as expected, the larger the taxation pressure imposed on the operators, the lower the available financial resources for network deployment.[13]
- A 50 per cent reduction in administrative time required for doing business is linked to an increase in ICT investment of 17 per cent. This suggests the relevance of government and institutional efficiency, in terms of reducing the required time for permits and other red-tape costs constraining network construction. The bureaucratic burdens related to institutional deficiencies can increase adjustment costs to investors, and as a result, to discourage investment decisions.
- OECD membership is associated with an increase in 36 per cent in investment, a result that supports the relevance for countries to become part of international organizations that promote sound regulations and good practices to enhance a business-prone environment. However, this result must be taken with caution as it may be affected by some upward bias. Countries belonging to the OECD are richer and more developed than those that are not

[12] The complete econometric results are presented in Table E.3 in Appendix E.
[13] This result is consistent with previous findings in the literature (Katz *et al.*, 2012; Katz and Callorda, 2019).

part of this organization. Even if the estimation performed controls for past investment and revenues, it is natural to expect more advanced economies to experience larger investments. On the other hand, the OECD membership is expected to be correlated with other variables proxying good regulatory frameworks and institutions; thus, the coefficient may be capturing some of those effects as well.

- Similarly, countries with a 5-year membership of the WTO are linked to a 17.5 per cent more investment than non-members, again pointing out at the relevance of being part of international organizations that promote good policy frameworks. Specifically, the WTO promotes principles[14] of non-discrimination (in terms of national and foreign products and services), openness (by lowering trade barriers), predictability and transparency (avoiding arbitrary decisions) and competitiveness (by discouraging 'unfair' practices). All these principles are essential for creating a business-prone environment.

To sum up, in terms of the specific variables being tested, if a country is aiming at increasing the investment in fixed and mobile telecommunications, the following changes should be implemented: tax reductions for the sector, as well as reduction of bureaucratic burdens that inhibit investment decisions. In addition, countries should evaluate the possibility of joining international organizations that promote good regulatory frameworks, or at least to incorporate their policy recommendations.

4. Drivers of performance and impact of mobile telecommunications

The availability of a full data set for the mobile sector[15] allows estimating the complete structural model as detailed in Table 1. The model starts with the econometric regression of the investment equation by introducing specific policy and regulatory reforms as explanatory variables. The focus will be on the assessment of the following regulatory reforms:

- the development of a national broadband plan;
- the assignment of converged licences;
- the possibility for mobile operators to voluntarily conduct spectrum sharing agreements;
- the introduction of the requirement of mobile number portability;
- the openness of the market to foreign operators for spectrum-based services; and
- the creation of a competition authority.

These variables are usually identified as part of regulatory best practices in the ITU ICT Regulatory Tracker. They represent three different public policy types:

- *Market-signalling policies*: this concept entails initiatives that, while they carry limited enforcement power, they embody a government belief or a strategic aspiration (such as development of the digital economy), which sends a 'signal' to the private sector to respond accordingly. A national broadband plan or a digital agenda are examples of this policy.
- *Conditional policies*: these policies formulate rules and 'conditions' under which the sector operates that act as enablers for ICT operators to maximize their business-case

[14] https://www.wto.org/english/thewto_e/whatis_e/what_stand_for_e.htm.

[15] The lack of reliable series of investment for fixed broadband technologies prevented running a complete structural model for fixed telecommunications. In addition, as the dependent variables of the remaining equations of the structural model are technology-specific (coverage levels, prices, penetration), it precluded running a complete structural model for the overall telecommunication sector (fixed and mobile).

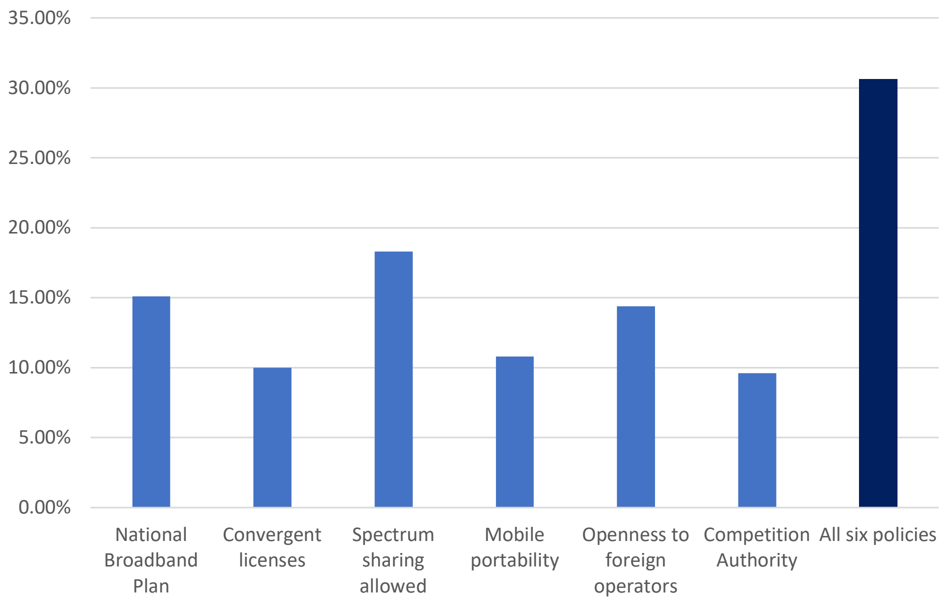
and make more profitable their investments. Spectrum sharing permits or the assignment of converged licences are some of these policies.

- *Specific regulatory obligations*: these policies are imposed as they expect to improve market dynamics. Such is the case of the requirement of mobile number portability.

All identified reforms boost mobile telecommunication CAPEX

The impact of each variable on capital expenditures were assessed first. In addition, the possibility of all policies being implemented simultaneously[16] was considered. The impact of each reform type and the cumulative set of all policies on mobile CAPEX is shown in Figure 6.[17]

Figure 6: Mobile CAPEX improvement after a simulated policy reform (contemporaneous effect)



Source: ITU
Note: Simulations reported in Tables E.9 to E.14 in Appendix E.

Model results highlight the different impact of specific policies in addition to the cumulative effect of all of them. While the effect of each regulatory initiative is significant, countries that implement all policies simultaneously drive an increase in investment levels over 30 per cent larger than those countries that do not implement any of them. This suggests the positive effects of carrying out all the simulated policy reforms simultaneously.

When considering the impact of each policy, the following results point to their independent contribution:

- The development of a national broadband plan (a market signalling initiative with limited enforcement power) has a positive impact, increasing mobile investment by 15 per cent. At a higher level, so-called 'signalling' policies that do not convey changes in

[16] For that purpose, a regulatory scale was built taking values from zero to six depending on the number of regulatory initiatives each country implements. In other words, a country that does not implement any policy is assigned a value of zero in the scale, while a country that puts in practice all of them will receive a value of six. Countries that implemented some of the policies (but not all), receive values between 1 and 5. We relied on this scale to compare the two extreme scenarios: countries promoting all six policies compared to those that do not implement any of them.

[17] The complete econometric results are presented in Table E.4 in Appendix E.

the environment or regulatory obligations, can exercise a positive impact in fostering investment and innovation. This suggests that political leadership in terms of implementing a digital agenda is crucial, reinforcing the necessity of a consensus and coordination for both infrastructure deployment and the regulation of the services to be provided, which in turn, accelerate innovation and boost investment. By 2019, of the surveyed countries, 89 per cent had already developed a broadband plan[18].

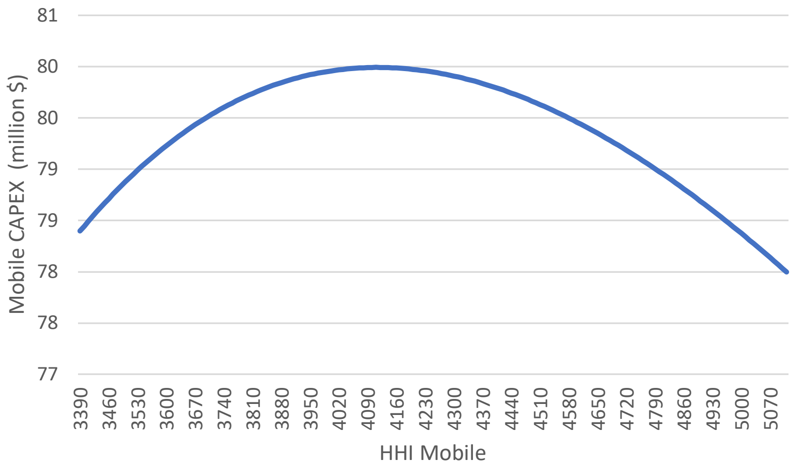
- Converged 'technology neutral' licences have a positive and significant impact on investment. Moving from service and network specific to converged licensing is associated with an increase of mobile investment of 10 per cent. Converged licensing constitutes a flexible approach, more adapted to technological advances, and contributes to maximize the financial returns of investments. On the contrary, rigid and technology-specific licences are not expected to keep up with the innovations and developments of the ICT sector. This finding could be extended to interpret it as the value of flexible regulatory frameworks.
- The possibility of signing up voluntary infrastructure and spectrum sharing agreements is associated with a 18 per cent increase in mobile investment. This practice allows to maximize the opportunities for operators to make investment profitable, creating incentives for network deployment. Network-sharing agreements can optimise the use of infrastructure, generally reducing costs, thus being beneficial for both service providers and consumers. Again, this variable can also be assumed to be a proxy for flexible a spectrum approach, usually considered as a necessary condition to maximize the development of mobile services.
- The introduction of mobile number portability has a positive effect of increasing mobile investment by close to 11 per cent. This is related to the fact that the policy renders the market more dynamic and competitive. Number portability lowers barriers for consumers to change mobile providers. As a result, operators have to strive and provide the best quality and services to retain their current subscribers.
- When the market is opened to foreign players, capital investment is stimulated, increasing by 14 per cent. Foreign investment facilitates the growth and development of the ICT sector, facilitating access to capital for network development and modernization, and allowing for the transfer of technology and know-how, leading to increased productivity, innovation and competitiveness.
- The existence of a national cross-sector competition authority is related to an increase in almost 10 per cent in mobile investment. The existence of a competition authority contributes to monitor multiple digital markets in order to avoid anticompetitive actions taken by operators with significant market power, potentially harming other market players, possible new entrants as well as consumers. However, it must be said that the link between competitive intensity and investment was found to be non-linear[19], as suggested by the 'inverted-U' theory developed by Aghion *et al*. (2005)[20]. Simulations performed with the coefficients from the estimated regressions provide evidence on the existence of an optimal market concentration level. Figure 7, in the sample considered, shows the optimal concentration level (that is to say, the one that maximizes capital investment) was found to be close to a Herfindahl Hirschman Index (equal to) equal to 4113.

[18] This indicator does not provide a sense of the quality of the plan; in other words, the publication of a national broadband plan is not the only determinant of investment impact. Its quality, process for building collaboration between the public and private sector and executive leadership are critical implementation components.

[19] The procedure to measure the non-linearity was based in the introduction of the logarithm of the HHI index both in levels and in squares as a regressor in the investment equation. As observed in Table E.4 in Appendix E, both associated coefficients were statistically significant, with the level variable reaching a positive value and the squared exhibiting a negative sign. This is what explains the 'inverted-U" in terms of concentration and investment.

[20] See extensive analysis of the research on this topic in Appendix A.1.1.2.

Figure 7: Mobile CAPEX and the optimal concentration level



Source :ITU
Note: Simulation using the parameters estimated in Tables E.4 in Appendix E, assuming the sample means for the remaining regressors beyond HHI.

However, other policy variables did not exhibit a significant impact on mobile market performance. That is the case, for instance, of infrastructure sharing obligations, spectrum band migration allowance, or permission for spectrum secondary trading.

The Inverted 'U' theory explaining innovation and capital investment

In general terms, ICT investment is determined by both the competitive imperative and a minimum market share to ensure an adequate return. The relationship between concentration and investment was formalized in a theory developed by Aghion *et al*. (2005) that posited that capital-intensive industries need to be moderately concentrated to ensure an appropriate level of innovation.

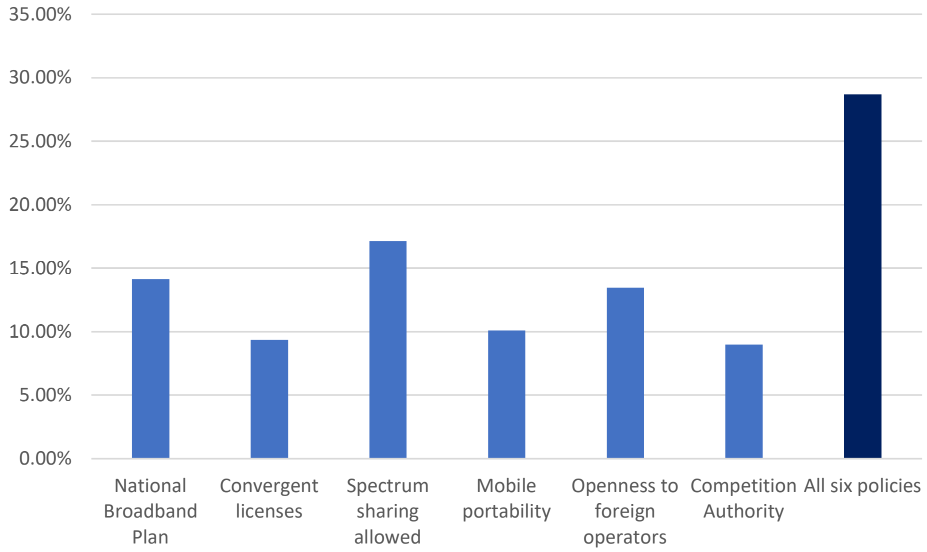
According to this formulation, investment increases with concentration up to an optimal point of moderate competition, after which, with increasing competitive intensity, the investment incentives begin to diminish. The reason driving this behaviour is that the incentive to innovate (and invest) is highest with moderate competition, while the implicit reduction in profits related to indiscriminate competition diminishes the drive to innovate. As a result, the relationship between competition and investment is not linear, but looks like an 'inverted-U'.

Research carried out through the years confirm this relationship. From a theoretical viewpoint, Huck *et al*. (2004) argued about the existence of an optimal number of players in these kinds of markets. Specifically, for the telecommunication sector, empirical research was able to provide support of the 'inverted-U' theory (see for instance Friesenbichler, 2007; Houngbonon and Jeanjean, 2016; Jeanjean, 2013; Pedros *et al*., 2018).

Expansion of coverage follows over the short term

As stated in the causality model, the increased investment resulting from policy initiatives will translate into mobile network coverage gains in subsequent periods (t+2), as depicted in Figure 8.[21]

Figure 8: Mobile network coverage increase after simulated policy reforms



Source: ITU
Note: Simulations reported in Tables E.9 to E.14 in Appendix E.

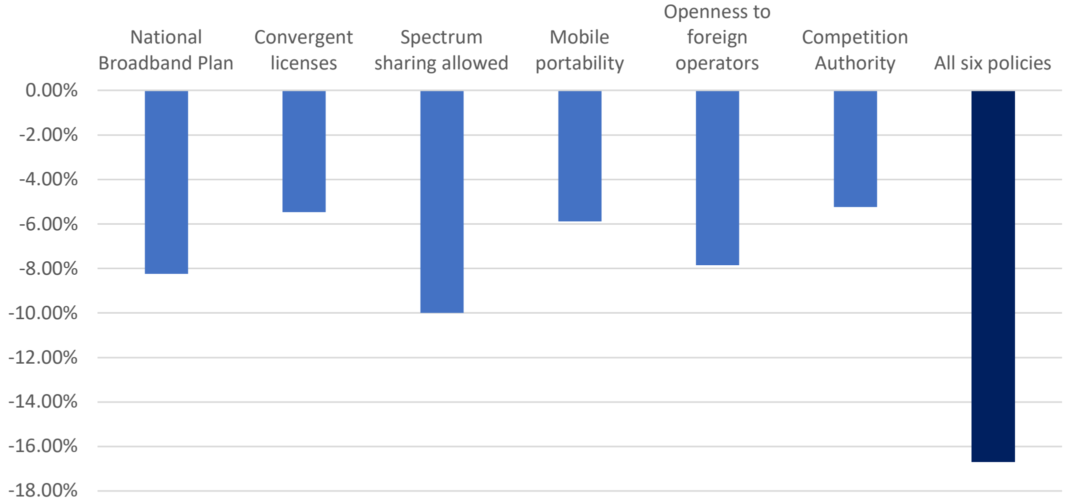
As shown in Figure 8, all simulated policies are expected to translate into effective coverage gains **two years** after the introduction of the policy and regulatory or institutional reform, ranging from a 9 per cent increase in the case of the introduction of a competition authority to 17 per cent in the case of allowing infrastructure and spectrum sharing agreements. On the other hand, when all the policies are jointly implemented, coverage increase reaches 28.6 per cent in t+2.

Additional investment spurred by policy and regulatory reform lead to lower consumer prices

In addition, coverage improvements resulting from past investments contribute to reduce prices, as the supply curve shifts to the right. Coverage gains can also be interpreted as the result of technological improvements, which from a dynamic perspective, usually translate into lower prices[22] (see Figure 9).

[21] Full estimation details for the coverage equation of the model reported in Table E.5 in Appendix E.
[22] Full estimation details for the price equation of the model reported in Table E.6 in Appendix E.

Figure 9: Price reduction after simulated policy reforms



Source: ITU
Note: Simulations reported in Tables E.9 to E.14 in Appendix E.

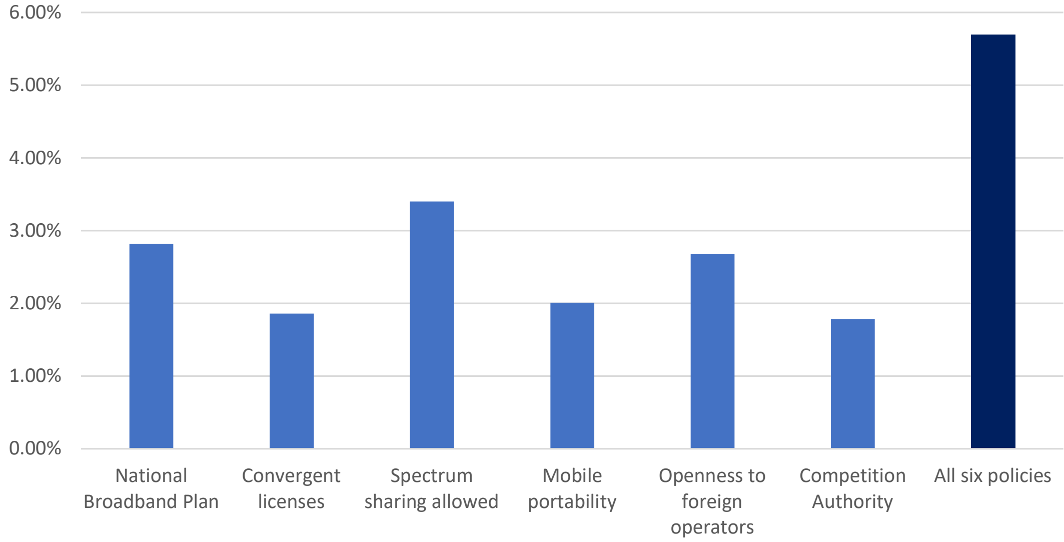
As depicted in Figure 9, the single policy that seems to provide the largest price reduction is that of allowing infrastructure and spectrum sharing agreements. This can be explained as follows: this policy not only creates incentives to increase investments (dynamic efficiency), it also stimulates competition in prices (static efficiency) by allowing, for instance, the market entry of Mobile Virtual Network Operators (MVNOs). Naturally, the largest price reduction takes place when all the six policies are implemented simultaneously (-16.7%).

When the right reforms for national markets are enacted, penetrations soar

In turn, coverage advances and price reductions will drive service adoption. The higher the coverage, the larger the market scope. On the other hand, by considering the price-elasticity of demand, lower prices will stimulate adoption. Therefore, mobile broadband penetration increases as a result of the simulated policy reforms, as detailed in Figure 10.[23]

[23] Full estimation details for the demand equation of the model reported in Table E.7 in Appendix E.

Figure 10: Increase in mobile penetration after simulated policy reforms

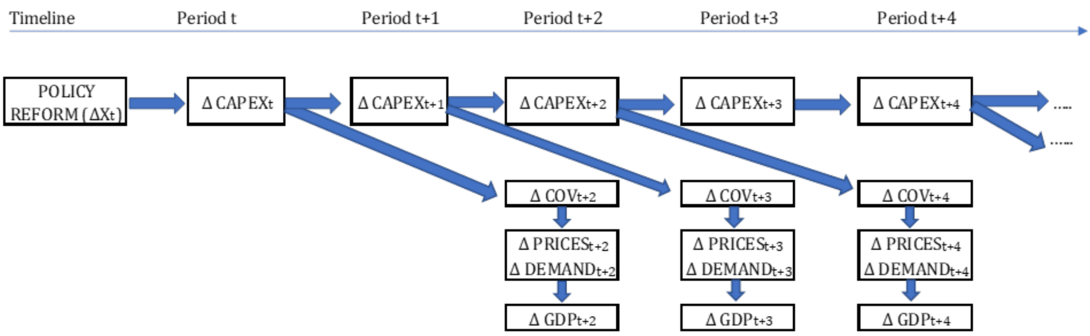


Source: ITU
Note: Simulations reported in Tables E.9 to E.14 in Appendix E.

Regulatory reforms targeted at broadband markets also generate positive macroeconomic impact

The increased broadband penetration resulting from policy reforms will generate macroeconomic gains. In order to assess the magnitude of this impact, the estimated coefficients from Katz and Callorda (2020) were used. These estimates indicate that an increase of 10 per cent in mobile broadband unique subscriber penetration yields a 1.5 per cent increase in GDP per capita. However, given the dynamics of the empirical model, the positive impact from policy and institutional reforms will translate into further gains beyond a single period, as capital spending in future years will continue to grow as a result of the improvements in its own past values. This economic flow of economic gains is summarized in Figure 11.

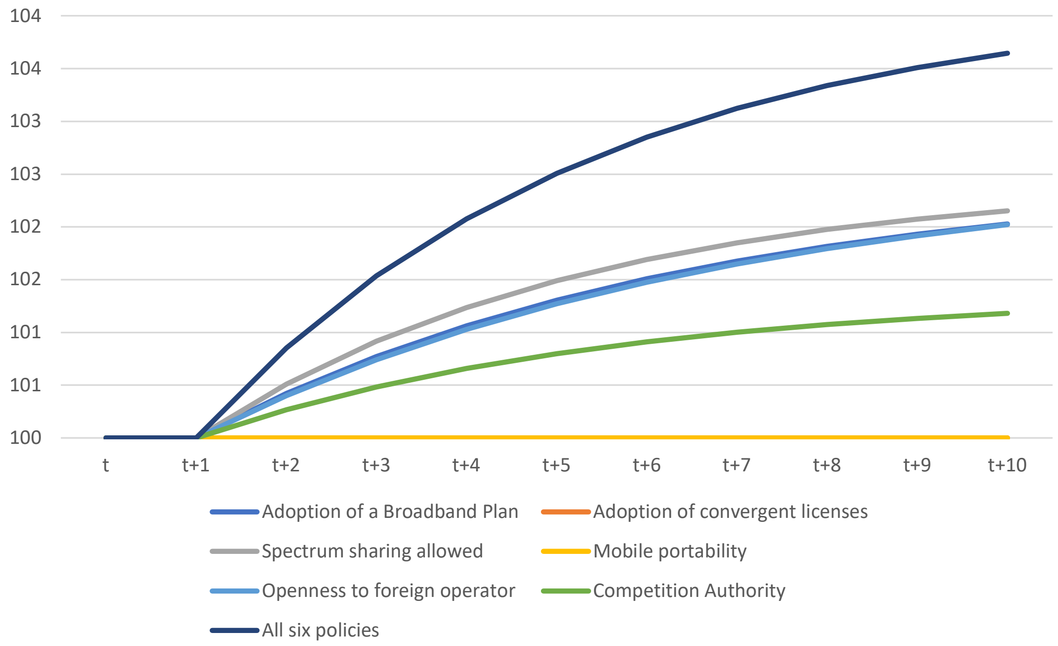
Figure 11: Dynamic economic gains after a policy reform implemented in period t



Source: ITU

Figure 12 depicts the cumulative evolution of GDP per capita in periods *t* to *t+10* after the simulated policy reforms. Naturally, the single policy reform that yields the largest gains in terms of GDP per capita is the one related to the biggest increase in investment, as is the case of the possibility for operators to sign up spectrum sharing agreements (increase of 0.51 per cent on GDP per capita in period *t+2*). In all cases, after reaching the highest GDP per capita growth rate in period *t+2,* the policy-related effect gradually decreases. This is what explains the concave curve reflecting the cumulative evolution of impact. The tendency of the curve to flatten is linked to the fact that the simulated scenarios represent only the effect of a single-time reform, assumed to take place in period *t*. The inertia of investment through the subsequent periods explains the extended positive impact in terms of GDP per capita.

Figure 12: Cumulative GDP per capita evolution after simulated policy reforms (base period t=100)



Source: ITU
Note: Simulations reported in Tables E.11 to E.16 in Appendix E.

5. Conclusions

This study complemented prior research and generated new evidence about the impact of the policy, regulatory and institutional framework on the performance of the ICT sector and on the national economy as a whole.

First, econometric models provided evidence of the relevance of the ICT Regulatory Tracker and each of the pillars - regulatory authority, regulatory mandate, regime and competition framework – to drive fixed and mobile telecommunication capital spending. Additionally, the pillars composing the ICT Regulatory Tracker have shown to be complementary among each other. For example, in the absence of a suitable regulatory regime, the influence of the regulatory authority and regulatory mandate is considerably diminished. In addition, tax reductions and the decrease of administrative burden on operations were also found to be relevant in the aggregate to stimulate investments. Finally, membership of international organizations, such as OECD or WTO, that promote good regulatory frameworks and policy practices, represent positive contributions to increasing capital expenditures.

Second, a structural model was estimated for the mobile sector, focusing on a set of specific policy reforms, namely the adoption of a national broadband plan, the introduction of convergent licences, the possibility for mobile operators to conduct infrastructure and spectrum sharing agreements, the requirement of mobile number portability, the market openness to foreign operators and the creation of a competition authority. All policies were found to yield increased mobile capital investment levels, which in turn translate into coverage gains, price reductions, higher adoption levels, and, ultimately, GDP per capita growth. That being said, not all the simulated policies have the same effect: allowing spectrum sharing agreements, promoting a national broadband plan and opening the industry to foreign operators stand out as the policies that exhibit the largest payback. In addition, as in the prior model, it is important to mention that policies are expected to complement each other.

The selected reforms evaluated in this study represent different approaches towards formulating public policy and regulation. First, some of the policies represent a signal sent by the State to operators that investment in ICT infrastructure is part of an overall country vision. That is the case of the adoption of a national broadband plan or a digital agenda. Other policies create suitable conditions for network operators to thrive. Such is the case of permitting infrastructure and spectrum sharing agreements, or providing convergent licences, as flexible approaches that help to maximize business opportunities and investment profitability. Finally, in some cases specific obligations are expected to improve market outcomes. That is the case of the requirement of mobile number portability. All in all, the evidence seems to suggest that a sound approach towards policy formulation should include a mix of market signals, conditions for operators to invest, and -only when necessary-, specific obligations.

This empirical evidence is expected to provide useful inputs to policy-makers in terms of a deeper understanding of the linkages between the regulatory and institutional context and ICT market outcomes, and on the characteristics that effective public policies should have. However, some caveats need to be made regarding the study results. Certain indicators are limited in terms of their full predictability. For example, the binary nature of some of the initiatives (i.e., existence of a broadband plan yes/no) does not provide an indication of their quality. Furthermore, some of the independent variables (particularly those related to institutional maturity) reflect a subjective judgement and they could therefore be prone to perception bias. In addition, technological progress might render some of the indicator's imperfect. For example, the coverage variable is measured with regards to 4G wireless technology and does not address causality with future 5G deployment.

On another note, the pandemic of COVID-19 is expected to have an incidence in the presented results. On the one hand, the GDP contraction experienced worldwide will surely reduce telecommunication/ICT revenues, therefore impacting negatively in the capital spending levels (investment equation). On the other hand, the lockdown period is expected to result in the enhanced use of digital technologies, thus representing an unobservable shock positively affecting adoption levels (demand equation). These effects will be econometrically measurable when 2020 data becomes available.

That being said, the results are quite powerful in terms of informing policy decisions. Regulators and policy-makers alike should assess the quality of the institutional framework guiding industry operations and examine whether some of the policies found to be critical in promoting an improvement of sector performance are in place. Even if they have been adopted, it is important to examine the policies in detail to determine how much they meet some of the international best practices.

Appendices

A. Research literature review

A.1 A causal framework

The focus of the research literature review is on three sets of variables to be assessed in terms of their interrelationship and causality: (i) ICT sector policies (competition, liberalization, spectrum, and taxation), (ii) ICT sector development (prices, innovation, and access), and (iii) macro-economic results. This review identifies the main components and links in the theoretical framework that will guide the analyses of interrelationships among a number of variables. Specific evidence in the research literature is provided in support of each link.

A.1.1 Primary causality

The study should address what are believed to be the two primary causal terms in the framework: (i) ICT sector policies formulated by policy-makers and regulators as influencing (ii) ICT sector market outcomes.

The main focus is on three sector policies to be studied: competition, liberalization and taxation. Since liberalization refers to the removal or loosening of restrictions on an economy or an industry with the purpose of stimulating the development of competition, the concept is subsumed within the analysis of competition model regulation, which includes the terms of access regulation, sector concentration, and monitoring of dominance. In addition to sector specific taxation, spectrum management has been added, which represents a policy aimed at regulating access to a key scarce input. Finally, a variety of sector specific regulations, such as quality of service, that might drive potential ICT sector market outcomes is considered.

To sum up, ICT sector regulation and related policies, considered to be the pillar of independent variables to be included in the causal framework, include:

- Competition (access regulation, concentration, dominance)
- Taxation (sector specific, such as taxes on Internet services, and general taxes, such as VAT)
- Spectrum management (band allocation, licensed and unlicensed framework)
- Other regulations (quality of service, sharing obligations, etc.)

On the other hand, sector market outcomes are measures of performance, and considered to represent the dependent terms in the primary causality, categorized as:

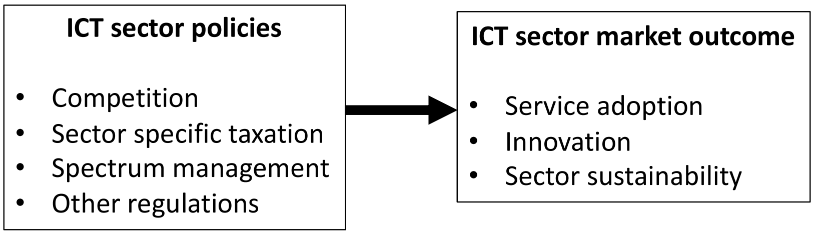
- Service adoption: conceived as a public good, the adoption of ICT services is a measure of well-being. Service adoption is a function of supply and demand factors; supply includes coverage, while demand is primarily a function of affordability (and therefore determined by prices), although it includes also variables such as digital literacy and relevance of content (linguistic and cultural)[24].
- Innovation: also considered under the economic term of dynamic efficiencies, innovation can be assessed in terms of product variety (technologies, service plans), feature functionality, and service quality (speed, latency).

[24] See Katz and Berry (2014).

- Sector sustainability: while generally not included in the measures of ICT sector performance, the profitability of private sector firms providing ICT services is a variable that drives the long-term sustainability of adequate investment and service quality.

The primary causality around which the theoretical framework will be structured is organized in the two terms described above (see Figure A.1).

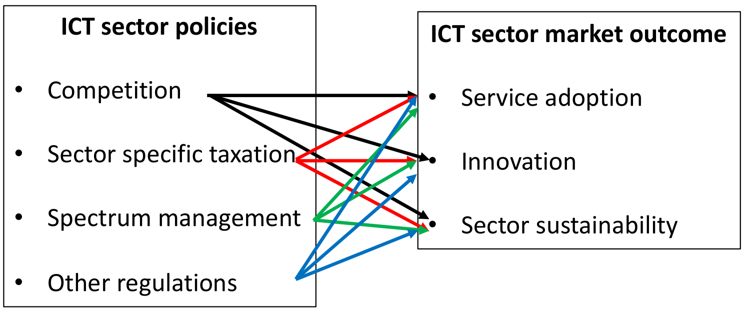
Figure A.1: ICT policies and sector market outcomes



Source: ITU

Research literature indicates that each independent variable comprising the ICT sector policies term drives changes in all three dependent variables. For example, the competition model has an impact on prices (static efficiencies) which in turn drive adoption, investment and innovation (dynamic efficiencies) and sector sustainability (defined as an industry that can thrive and provide benefits to consumers).[25] As a result, causality between both terms, policies and market outcomes, should be disaggregated into twelve links (see Figure A.2).

Figure A.2: ICT policies and sectoral outcomes – causality links



Source: ITU

As depicted in Figure A.2, each independent variable drives an effect on all three dependent ones. The remainder of this chapter reviews the research literature for each link. In reviewing the literature, methodological implications are drawn for developing the econometric analyses.

A.1.1.1 Competition and service adoption

Research assessing the impact of competition on ICT service adoption initially focused on the effects of privatization on sector performance. While it is recognized that privatization of a State-owned service provider does not necessarily involve a definition of the competition model, this initiative was considered to be the initial step towards the development of competition. Following the development of the industry, the second body of research addressed the link

[25] This last variable, while rarely addressed in the literature, is critical. For example, a competition model that results in an unlimited number of players driving inordinate amount of price competition might benefit consumers but will be unsustainable in a capital-intensive sector such as telecommunications.

between industry liberalization and service adoption focusing on the relationship between competition and prices (or statistic efficiencies). Finally, the third body of research does not analyse the impact on prices but focuses implicitly (or through control variables) on the transitive relationship between policy and service adoption. These three research bodies will be reviewed for voice telecommunications, fixed broadband and wireless telecommunications.

Privatization and telecommunication development

Two studies are particularly relevant in the study of the effect of privatization and sector development:

- Wallsten (2001) undertook an econometric analysis of the effects of telecommunications reforms in developing economies, using a panel dataset of 30 countries in Africa and Latin America from 1984 through 1997. He estimated two equations, first the telecommunication indicators as a function of the number of mobile operators not owned by the incumbent, a dummy variable indicating whether the incumbent was privatized, a dummy variable indicating the existence of a separate regulator and a vector of control variables. In the second equation, to explore further effects of regulation, Wallsten allowed the interaction of the regulation dummy with the privatization dummy and with the number of competitors. It was found that competition is significantly associated with increases in per capita number of telephones mainlines, payphones, and connection capacity, and with decreases in the price of a local calls. Privatization by itself was significantly associated with a decreased capacity but, when combined with the existence of a separate regulator, was significantly associated with increases in connection capacity and mainlines per capita. The biggest methodological issue raised in the study was that competition, privatization and regulation may be endogenous to reforms.
- Li *et al*. (2004) studied the effect of privatization (full and partial) and competition on a group of telecommunication performance variables. Each telecommunication performance variable was modelled as a function of a set of country economic indicators and telecommunication reform variables. The study found that full privatization has an important positive effect on increasing fixed-line and mobile densities, while competition only has a significant effect on mobile density. Full privatization was found to increase the industry output but also prices. In turn, privatization increases labour productivity by almost 50 per cent and competition by almost 10 per cent.

Regulatory unbundling and fixed broadband service adoption

The study of policy impact on broadband diffusion has primarily emphasized the assessment of the relative importance of service-based versus platform-based competition with a focus on the United States of America, the European Union, and OECD countries. Access regulation has typically relied on requesting the incumbent operator to unbundle the last-mile loop to competitors (LLU). Accordingly, several studies were surveyed on the impact of regulatory unbundling and broadband service adoption:

- Ford and Spiwak (2004) evaluated the influence of unbundling on both the general availability of broadband service as well as whether the service is provided competitively at a state level for the United States. Ford and Spiwak modelled two equations expressing the dynamic of universality of access and competition. Each variable was expressed as a function of the same exogenous variables (LLU price and cost, income, density, and time). The dependent variables considered were the universality of access (percentage of postal codes in a state that have at least one provider of broadband services), and competitive access to broadband service (percentage of postal codes in a state that have at least four providers of broadband services). The study found that both broadband availability and competition appear to be driven primarily by rural population, time, and unbundled loop prices, and that higher loop prices reduce both the universal and competitive availability of broadband services.

- Garcia-Murillo (2005) studied two questions: (i) how unbundling policies affect decisions to offer broadband access to the Internet and (ii) which factors contribute to the adoption of broadband. A two-stage analysis was used in this case: first the factors that affect the availability of broadband services in a country were identified. Second, a set of models aimed at identifying the factors influencing the number of broadband subscribers. The sample of over 100 countries was divided in four types of countries: low, lower-middle, upper-middle, and high-income. The variables that were utilized included an unbundling dummy variable, ownership dummies (privatized, state-owned, semi-privatized), and competition dummies (monopoly, duopoly, partial competition, full competition). The analysis showed that unbundling an incumbent's infrastructure can result in a substantial improvement in broadband deployment for middle-income countries, but not for high-income countries. However, the study relied on cross-section data, only considered a number of players, and did not distinguish between inter- and intra-platform competition.
- Distaso et al. (2006) focused on the role of competition in promoting broadband adoption. They studied the impact on broadband adoption of policies aimed at fostering competition between platforms and policies aimed at promoting intra-platform competition within the DSL market. They tested the results of a theoretical platform competition model based on a framework of oligopoly competition between differentiated products using a static and a dynamic data panel. They tested three hypotheses: (i) the lower the price for local loop unbundling (LLU), the higher broadband adoption, (ii) a reduction in the price of LLU may be more effective in promoting broadband the lower inter-platform concentration, and (iii) the lower the HHI indices, relative to both inter- and intra- platform concentration, the larger total broadband access. The data set was compiled for fourteen European countries. They found that competition between different platforms seems to be one of the main drivers of broadband uptake and that as this level of competition also raises the positive effect of a reduction of the price of LLU on broadband uptake. However, a possible endogeneity problem between GDP and broadband penetration was not considered.
- Cava-Ferreruela *et al*. (2006) analysed the factors that could affect the supply and demand of broadband. They specified two equations to explain broadband supply and broadband demand. The variables used to estimate the supply side were infrastructure availability, infrastructure investment and market competition, while the demand side was estimated by relying on telecommunication services penetration, Internet indicators, economic indicators, demographic indicators, education indicators and social indicator for thirty OECD countries. Their study found that the most influential factors for broadband infrastructure supply are the economic level of the country, the existence of another platform and the demographic distribution of the population. The results showed that the availability of DSL access networks is dramatically higher for countries with competing broadband infrastructures (an average of 10 times greater).
- Wallsten (2006) explored some of the determinants of broadband penetration and speed of available Internet connections in OECD countries. This study took into account unbundling regulation, types of wholesale price regulation and types of collocation implemented. The dependent variables were broadband penetration and speed, while the exogenous variables included dummies for the types of unbundling, dummies for the wholesale price regulation, dummies for collocation implemented, main telephone lines per 100 people, population density and Internet price. The data set comprised 30 OECD countries over five years (1999-2003). The study found that full local loop unbundling is not obviously correlated with broadband penetration, while subloop unbundling is robustly negatively correlated with broadband penetration. In turn, the effect regarding comingling collocation is generally positive, virtual collocation negative, and regulatory approval for collocation charges negative.
- Boyle *et al*. (2008) conducted a study to assess the results of a study commissioned by the OECD that found a statistically significant effect of unbundling on broadband uptake (OECD, 2007). They re-estimated the model in order to verify the significance of the OECD study results. The dependent variable was broadband connections per 100 population while the independent variables included the number of years since the implementation of LLU (measure of unbundling presence), monthly price per megabit-second of DSL, share

of the population aged between 35 and 44 years, percentage of the population defined as urbanized, non-DSL connections as a percentage of total broadband connections (measure of broadband competition), and the number of years that the broadband technology has been available for each country. Data was compiled for 24 OECD countries in 2002 and 30 OECD countries in 2005. This study properly accounted for the error structure of the data and found that the statistical significance disappears. It was concluded that the OECD report could not be used to justify the view that local loop unbundling leads to greater broadband uptake. Moreover, this study concluded that the technology diffusion effect should be considered. To deal with this, it included in the specification a variable that controls for the time that broadband has been available in a particular country to locate a country in a point of the technology diffusion curve.

- Lee *et al*. (2008) explored influential variables driving global broadband diffusion by examining several factors – such as platform competition, information and communication technology (ICT) use, content, broadband speed, income, population density, education, price, and LLU. In their multiple regression analysis, they exclude the LLU variable because they considered that platform competition and LLU are not mutually exclusively policy tools. To analyse the LLU effect, they used a one-way analysis of variance. The findings in the paper showed that platform competition, LLU, broadband speed, information and communication technology use, and content contribute to global broadband adoption. The impact of platform competition is strong when market share of dominant technology and non-dominant technology is similar. This study did not differentiate between the various types of LLU and their respective prices. The study used only cross-sectional data and did not consider time variables.
- Bauer *et al*. (2004) failed to identify an impact of competition policy on broadband penetration, although this could be related to the early time at which the research was conducted, which forced them to rely on very preliminary data sets. They used cluster analysis to identify homogenous subgroups of countries with similar policy characteristics across three areas - unbundling, the separation of cable and telephone company ownership and the availability of government funding to support broadband deployment- to reduce the number of independent variables. Having defined these clusters, they used a supply and demand framework and derived a reduced form model, which was used in the econometric analysis. It was concluded that competition does not have a statistically significant effect on penetration. Moreover, it could have a negative effect, implying that more intense competition in the telecommunication market correlates with a lower broadband penetration rate. This finding, while contradicting later studies of broadband diffusion, could also point to the oligopolistic structure of broadband in which a more open market structure could lead to market fragmentation and, potentially, lower deployment.

The reviewed studies reflect that, with very few caveats, platform-based competition rather than service-based around regulatory unbundling appears to be the key variable explaining broadband deployment. Platform-based competition is one of the main drivers of broadband uptake, as concluded by Distaso *et al*. (2006), Cava-Ferreruela *et al*. (2006), Boyle (2008), Wallsten (2006) and Garcia-Murillo (2005) (although in this case for high income countries). Lee *et al*. (2008) determined that the impact of platform-based competition is stronger when the share of technologies reaches parity (this related to competitive intensity). Conversely, most studies provided limited evidence on the importance of LLU in fostering broadband adoption.

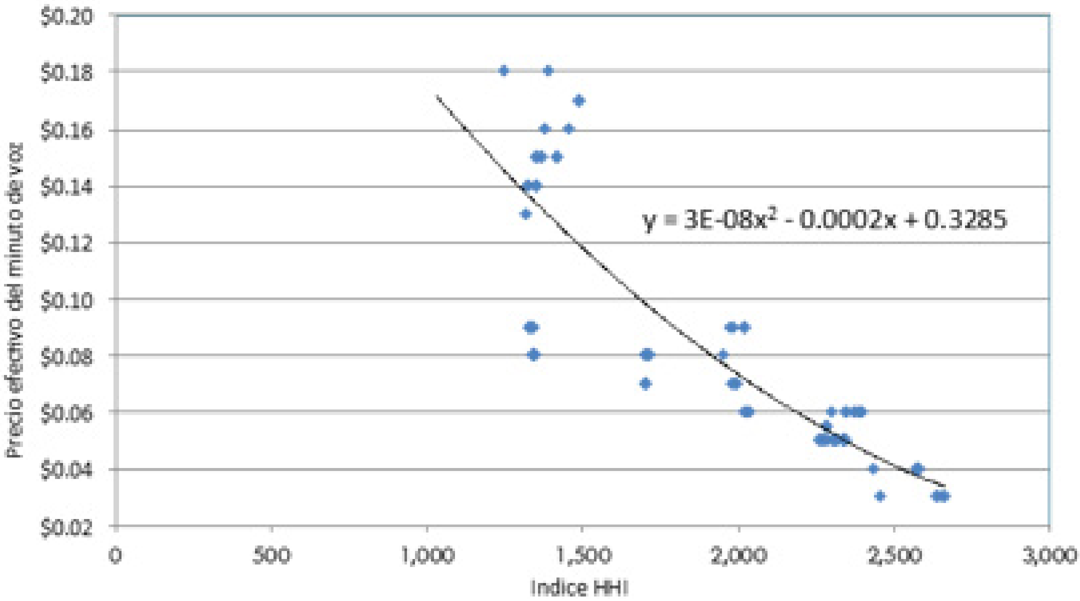
Competition and wireless pricing

In addition to studying the impact of privatization on ICT sector performance, and fixed broadband unbundling on adoption, other research studies focused on the relationship between competition and wireless prices. For example, Grzybowski (2005) studied the impact of regulatory policy on prices and demand for mobile telecommunication services across 15 European Union countries between 1998 and 2002. The endogenous variables in this study were mobile penetration and price of mobile services, while the exogenous ones are divided in three categories: a set of regulatory variables, a set of cost variables and a set of miscellaneous variables. The study estimated a reduced form model with two equations: first the penetration of mobile services (demand side) and secondly the price of mobile services (supply side). The main conclusions of this study were: (i) liberalization of fixed telephone lines have a negative impact on prices and a positive impact on the demand for mobile services while (ii) the introduction of mobile number portability has a negative impact on prices.

After the initial studies documenting the relationship between competition on prices, research turned to focus on analysing the impact of wireless mergers on pricing. The key question in this case was whether competition could be beneficial to consumers in terms of prices or whether moderate concentration could be instrumental in optimizing static efficiencies. For example, in an ex-post analysis of two European wireless mergers, Aguzzoni *et al*. (2015) demonstrated that one of the transactions did not result in price increases in the short and medium term, while in the second one prices increased, although such effect could not be attributed to the transaction itself. The conclusion emphasized that the study of the impact of consolidations on pricing has to be conducted carefully acknowledging the specificities of each transaction (such as the competitive intensity between the merged carriers, the number of remaining operators after the merger, and the type of remedies imposed by the regulator ex post). Additionally, the analysis raised an important methodological issue in relation to the impact of mergers on prices. Given the tendency towards the decrease of prices of telecommunication services, it is important to consider the influence of a merger in the context of a counterfactual scenario (in other words, if prices diminished after the merger, can the decline be directly attributed to the transaction?).

In fact, the experience of the telecommunication industry in advanced economies demonstrates that the transition from fragmented to consolidated industries implies a reduction in telecommunication service pricing (see for example in Figure A.3 the relationship between the Herfindhal Hirschman Index and the price of a mobile minute in the United States of America).

Figure A.3: United States of America: Relation between the Herfindahl-Hirschman Index and the Price of a mobile minute (2000-2015)



Sources: GSMA Intelligence; Telecom Advisory Services analysis

A.1.1.2 Competition and innovation

The most important body of research on the relationship between competition and innovation focuses on the impact on capital investment, leading in turn to network deployment and, consequently, innovation. As for empirical evidence, a relevant contribution to research has been that of Alesina *et al.* (2005), which estimated the effect of overall regulation pressure in several sectors, including telecommunications, for a sample of OECD countries from 1975 to 1998, finding a negative effect of regulation intensity on investment levels. While Alesina *et al.* (2005) analysed overall regulatory pressure, this chapter will focus on reviewing studies that tried to assess the impact of specific regulations on investment and innovation.

Access obligations and broadband investment

As reviewed above, platform-based competition appears to be the key variable explaining broadband deployment, as concluded by Distaso et al. (2006), Cava-Ferreruela *et al*. (2006), Boyle (2008), Wallsten (2006), Lee *et al*. (2008), and Garcia-Murillo (2005). In turn, competition in wireline has been found to have a positive statistically significant impact on network deployment (Li *et al*, 2004; Grzybowski, 2008; Wallsten, 2001). However, when imposing access obligations, such as LLU, investment and innovation incentives may be diminished, according to a large body of the literature. In the case of broadband, access regulation discourages investment by incumbents and individual entrants even as overall total investment may increase. In a similar vein, Jorde *et al.* (2000) stated that mandatory unbundling tends to decrease investment incentives, while Hausman (1999) concluded that mandatory unbundling is a failure because it neglects the role of sunk and irreversible investments in the telecommunicators sector. Similarly, Grajek and Roller (2012) concluded that mandated access intending to reduce entry barriers may undermine the incentives of incumbents to invest in networks. Three specific studies can be highlighted in detail:

- The above-reviewed study of Cava-Ferreruela *et al*. (2006) analysed the factors that could affect the supply of broadband, considering infrastructure availability, infrastructure investment and market competition. Their study found that the most influential factors for broadband infrastructure supply are the economic level of the country, the existence of another platform and the demographic distribution of the population. The results showed that the availability of DSL access networks is dramatically higher for countries with competing broadband infrastructures.
- Waverman *et al*. (2007) studied the impact of access regulation on investment in access infrastructure[26]. Using an unbalanced panel data, they sought to capture two effects of a change in the intensity of access regulation, as measured by the LLU price. These were (a) the substitution between LLU-based broadband and broadband offered over alternative access platforms, and (b) the impact of a change in the LLU price on the size of the overall broadband market. The dataset is derived for 12 countries in the Europe region. The main findings of this study were as follow: (i) lower local loop prices cause a strong substitution from broadband offered over alternative access platforms towards LLU-based broadband offerings. This substitution ultimately results in substantially lower investment in these alternative access platforms. (ii) A reduction of 10 per cent in LLU price causes an 18 per cent fall in the subscriber share of alternative infrastructure. Thus, intense access regulation (as measured through the LLU price) weakens facilities-based competition and the benefits that such competition delivers. (iii) This fall in subscriber levels has the impact of reducing investment in alternative access platforms in both short term and the long

[26] Including either alternative or new access platforms (Investment in infrastructure that offers genuine last-mile alternatives to the existing copper-wire network of the incumbent telecommunication operator).

term. The study concludes that unbundling tends to weaken facilities-based competition and reduce infrastructure investment.

- Friederiszick *et al*. (2008) analysed the link between entry regulation and infrastructure investment for a sample of 180 fixed-line and mobile operators in 25 European countries over a period of 10 years, finding that entry regulation discourages infrastructure investment by entrants, but has no effect on incumbents of fixed-line telecommunications. They did not find significant impact of entry regulation on investment in mobile telephony.

It must be said, however, that access regulation has its advocates. In particular, Cave and Vogelsang (2003) and Cave (2006) stipulated the theory of "the ladder of investment", by which providing entrants, successively, with different levels of access, while inducing them to climb the ladder by setting an access charge that increases over time or by withdrawing access obligations after some pre-determined date, would make service-based entry and facility-based entry complements in promoting competition. However, it must be said that the "ladder of investment" theory has been criticized, both from a theoretical and empirical standpoint (see Cambini and Jiang, 2009, for a complete literature review).

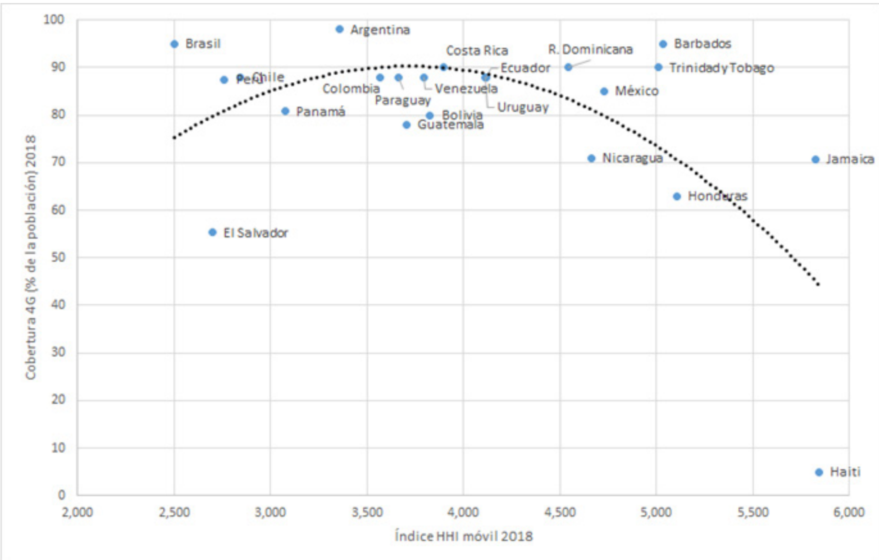
Industry concentration and innovation

At a more general level, the relationship between competition and innovation was formalized in a theory that posited that capital-intensive industries need to be moderately concentrated to ensure an appropriate level of innovation. The argument was formulated by Philippe Aghion and his team at Harvard University which presented the idea of the 'inverted-U', which synthesized two different theories developed through the years linking innovation and competition. On the one hand, Schumpeter (1942) developed a theory of innovation and creative destruction, establishing a negative link between competition and incentives to innovate. The rationale of this theory was based on the fact that lower competition levels imply higher expected returns from innovation. On the other hand, Arrow (1962) argued that more intense competition yields larger innovation activity, due to competitive pressures that push enterprises to innovate to gain market share. Both Schumpeter and Arrow views are incorporated in the framework formulated by Aghion *et al.* (2005) through the 'inverted-U' theory. According to this theory, the relationship between competition and innovation is not linear, but looks like an 'inverted-U', stipulating that innovation increases with competition up to an optimal point of moderate competition, after which, with increasing competitive intensity, the innovation incentive (and by implication to invest) begins to diminish. The reason driving this behaviour is that the incentive to innovate (and invest) is highest with moderate competition, while the implicit reduction in profits related to indiscriminate competition diminishes the drive to innovate. The objective is, therefore, to determine what is the optimal point of industry concentration where the incentives to innovate (and invest) are maximized.

Turning now to the ICT sector, the hypothesis guiding this body of research is that, based in part on the high economies of scale, competition among a limited number of vertically integrated operators would be moderate and therefore close to the optimal concentration point that maximizes investment and innovation. Even if competition is known to be an important market dynamic factor to promote investment and innovation (as seen before in the reviewed literature), the nature of the telecommunication sector (with large fixed and sunk costs) makes this relation a complex one. Turning to the optimal point of industry concentration argued by the 'inverted-U' theory, economic research has tried to determine which is the optimal number of participants in a market that maximizes static (prices) and dynamic (innovation) efficiencies from the perspective of the consumer, while ensuring a certain degree of profitability for the sector. Starting with Selten (1973), who famously stipulated that "four are too few and six are too many", the range in the number of players has been progressively revised through the years until Huck *et al.* (2004), stated that while two players can tacitly collude, four can be too many (that is to say, could lead to a suboptimal market outcome). Accordingly, the optimal market structure in the telecommunication sector in terms of maximizing consumer surplus, economic impact and sector sustainability, is approximately three or a maximum of four infrastructure operators. This quantity of players ensures a competitive intensity that is enough for generating a maximum amount of consumer welfare (lower prices but, more importantly, good products). Therefore, the 'inverted-U' theory helps to understand the link between the number of firms and the generation of economic efficiencies.

Usually, telecommunication investment is determined by both the competitive necessity and a minimum market share to ensure its profitability. Data analysis usually provides evidence of the 'inverted-U'. As an example, Figure A.4 shows the correlation between market concentration and 4G coverage (an indicator of innovation and investment) in Latin America for 2018.

Figure A.4: HHI and 4G coverage correlation in Latin America (2018)



Source: GSMA Intelligence, Telecom Advisory Services analysis

As for the empirical literature in support of the 'inverted-U' theory, Friesenbichler (2007) was able to show this relationship between concentration and investment. In turn, Kim *et al.* (2011) analysed the link between concentration and investment in the mobile segment using data from 58 operators in 21 OECD countries between 2000 and 2008. Their results pointed out to a positive relation between mobile concentration (measured by HHI) and investment (measured as the ratio CAPEX/revenue) for the specific HHI ranges of their sample. Similarly, Houngbonon and Jeanjean (2016) found an 'inverted-U' relationship between mobile operators' margins and investment. For a sample of 2,770 observations, they found an investment-maximizing EBITDA margin of 38 per cent. Coincidentally, Howard *et al.* (2015) stated the maximizing-investment point in 37 to 40 per cent of the EBITDA margin. In turn, Jeanjean (2013) found evidence of enterprise investment below optimal levels in situations where competitive intensity is very large, due to low expected returns. In the same vein, Kang *et al.* (2012) found a positive link between market concentration and investment for the Chinese mobile market. Finally, Pedros *et al.* (2018) concluded that, on the basis of an econometric analysis of 26 operators in 13 Latin American economies between 2001 and 2016, that the investment-maximizing point of the 'inverted-U' was located at an EBITDA margin of 32 to 38 per cent. By considering that investment conveys better service quality, using data from 52 operators between 2013 and 2016, the authors determined that those markets with two or three operators deliver services with downloading speed of up to 8 Mbit/s (a good service metric at the time).

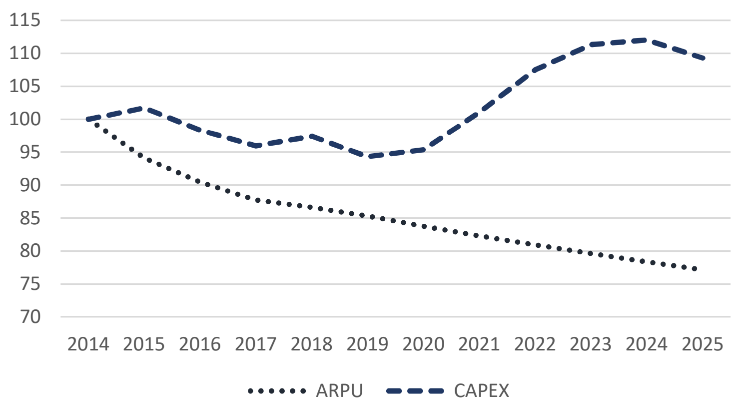
It is worth mentioning that the "inverted-U" theory notwithstanding, telecommunication investment is determined by multiple factors beyond market structure. For instance, Elixmann *et al*. (2015) pointed out that mobile CAPEX is conditioned by demand structure (income level, smartphone penetration, video content, etc.), deployment costs (density of base stations, framework for infrastructure sharing), spectrum availability, and competition model (HHI, quantity of players, presence of a 'maverick' operator).

A.1.1.3 Competition and sector sustainability

As mentioned above, sector sustainability is generally not included among the measures of ICT sector performance, although it is currently a major source of concern for operators. In particular, the profitability of private sector firms providing ICT services is a variable that drives the long-term sustainability of investment and service quality. However, this causal link has not been widely studied by the specialized literature.

The sustainability argument is as follows: competition intensity has been bringing prices down, benefiting consumers as a result. However, the same competitive pressures are pushing operators to invest and innovate in the latest technologies. This duality can be clearly analysed through Figure A.5 for the case of the global mobile segment: while investment is expected to increase towards 2025, boosted by the race to deploy 5G networks, revenue per user exhibits a consistent downward trend.

Figure A.5: Mobile CAPEX and ARPU



Source: GSMA Intelligence, Telecom Advisory Services analysis

This is the result of competitive dynamics that push the market forward, benefiting consumers. In this context, ICT sector authorities should be aware of the possibility that specific policies and regulations may induce costs that can have an impact on sustainability, with undesired effects on investment and quality. Similarly, competitive pressures for telecommunication operators from other actors of the digital ecosystem (namely, Over the Top players) should be done under the basis of flexible frameworks and not in situation of distortions created by asymmetries.

A.1.1.4 Sector specific taxation and service adoption

The digital eco-system is taxed by multiple levies at all stages of its value chain:

- telecommunication operators;
- telecommunication consumers (including wireless and broadband users);
- Internet service providers;
- over the top players (comprising content providers, digital advertisers, and e-Commerce players); and
- applications developers.

Telecommunication operators typically pay corporate taxes on profits but are also expected to contribute at several levels. First, in many countries' operators pay import duties on equipment purchased from overseas suppliers. Second, service providers pay property taxes on buildings and land owned where equipment is installed. Third, telecommunication operators also pay sales taxes on equipment purchased. Sales taxes can be collected at three levels: national, state or province, and local. Finally, operators pay also taxes on local and international interconnection revenues.

Consumption in the telecommunication industry is affected by several types of taxes. As mentioned above, some taxes are directly borne by the consumer (e.g., fees attached to the acquisition of devices), while others, such as sales tax on services, while included in the subscriber bill, are shared by providers and consumers. In most countries, wireless users pay taxes at the time-of-service acquisition (generally linked to handset activation) and on an ongoing basis (linked to service delivery). Three types of taxes exist in the wireless services sector:

- Value added or sales tax: most countries impose some form of Value-Added Tax, a general Sales Tax or similar consumption tax as a per cent of the total monthly bill;
- Telecom specific taxes: some countries charge an additional special communications tax as a per cent of the service bill;
- Fixed taxes: in addition to the tax as a percentage of usage, some countries charge a fixed tax that could be either driven by general communications or wireless usage.

In addition to service-based taxes, other levies can be imposed on handsets (related to activation):

- value-added or sales tax: these represent the taxes paid directly by the consumer at time of purchasing a subscription or handset, as well as when exchanging the device;
- customs duty: this tax is already included in the retail price of the handset;
- Other taxes: telecommunication-specific taxes on handsets (e.g., royalties calculated on the cost of handset); and
- fixed taxes: special fixed duties on handset, such as ownership fees and fees for recycling[27].

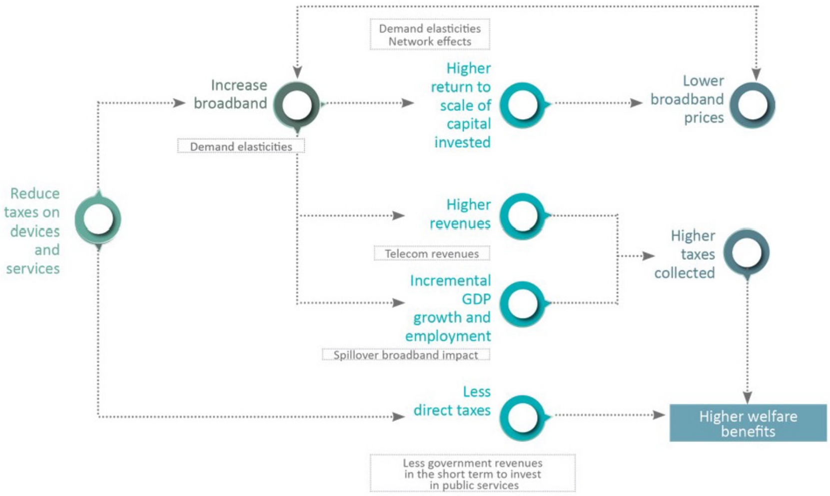
Broadband consumption taxes are not uniformly applied across countries. They take the form of taxation on Internet service providers, which in turn levy these charges on consumers. In some cases, since broadband is considered to be a critical socio-economic need, regulators have chosen to exempt broadband service from any consumption tax. In other cases, governments consider the ever-growing Internet access an attractive source of revenue and therefore, subject to taxation.

Katz (2015) reviewed and discussed policy issues related to the taxation of firms operating within the digital sector, as well as levies imposed on consumers purchasing digital goods and services. The assessment intended to provide answers to some relevant questions, such

[27] In Switzerland for example, 1 CHF is added to the price of all electronic appliances as an anticipated recycling fee.

as what the appropriate level of taxation and which services should be taxed. As explained in Figure A.6, the study described that a reduction of taxes on telecommunication services and devices may have a positive impact on service adoption as a result of demand elasticities. The increase in adoption improves the number of households connected (in fixed broadband) and the number of mobile broadband subscribers per infrastructure deployed.

Figure A.6: Virtuous circle of tax reduction on broadband devices, equipment and services



Source: ITU GSR-16 Discussion Paper, The impact of taxation on the digital economy

This increase in penetration enhances the return on networks which, in turn, allows the broadband service provider to lower prices, having a further positive impact on penetration. At the same time, an increase in broadband penetration has direct and indirect effects. On the direct side, it means an improvement in the revenues of broadband operators. On the indirect side, it enhances the contribution of broadband to economic growth and employment. Both effects increase the taxable base, which in turn grows the collected taxes beyond the amount foregone by reducing taxes on broadband devices and services. This effect yields higher welfare benefits.

A.1.1.5 Sector specific taxation and innovation

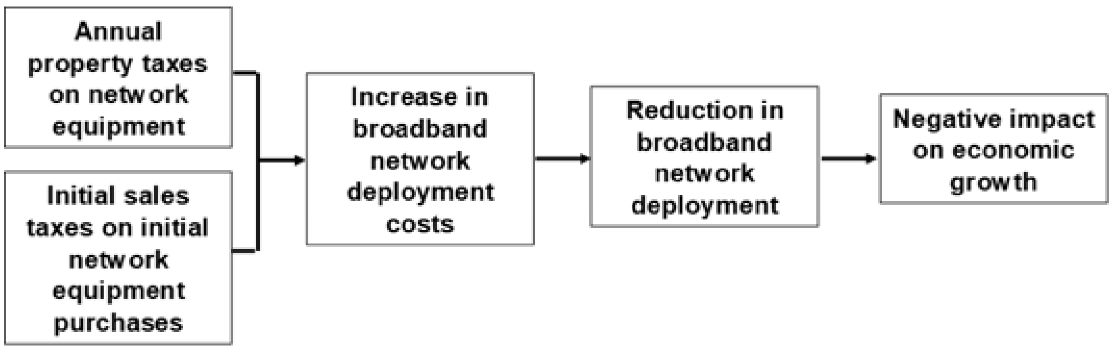
Beyond taxes on Internet consumption, ISPs can also be subject to sector specific levies which may affect investment and innovation. These could appear in the form of conventional corporate taxes, sales taxes on initial equipment purchase, indirect taxes on equipment to be installed at customer premises, and property taxes for physical assets.

Sales tax on initial equipment purchase is another conventional way by which telecommunication operators contribute to the treasury. As in the case of telecommunication operators, sales taxes are collected at either the national or federal, state or provincial, or local municipal level. Rates in this case could reach up to 10 per cent, to which customs duty on network equipment should be added. In Chile, for example, the customs duty is 6 per cent. In Mexico, the duty on imported network equipment varies by type of device, ranging between 5 and 15 per cent[28].

Another type of imposition affecting telecommunication operators is the property tax. For example, in the United States of America these operators pay property taxes for the physical assets they own in each state, as well as sales tax on the equipment purchased to support the delivery of broadband service. Payment of property taxes is based on the notion that broadband providers are 'utilities', and as such, they need to pay taxes originally established for railroads. The amount is calculated by valuing the entire business enterprise, rather than summing up the fair market value of specific fixed assets owned by the business[29]. The key ratio in determining the tax to be paid is the so-called 'assessment ratio', which is the proportion of the property value that the tax rate is applied in establishing the amount to be paid in property taxes. In an example of sector discrimination, a number of states define higher assessment ratios to the property of telecommunication companies than the ratio applied to property of general businesses. In another case of discriminatory practices, some states in the United States apply higher tax rates to the property of broadband providers companies. The Colombian government also collects property taxes ranging from 0.1 to 1.6 per cent of the value of physical assets.

Direct taxes (particularly annual property levies on network equipment and sales taxes imposed on initial network equipment purchases) imposed on ISPs have a negative economic impact. The underlying causality of this effect is depicted in Figure A.7.

Figure A.7: Impact of taxes on broadband network investment



Source: ITU

According to the logic presented in Figure A.7, taxes on network equipment in the two dimensions mentioned above – property taxes and sales tax on equipment - tend to affect the deployment of broadband infrastructure by telecommunication carriers and cable TV operators. Suppliers of broadband services have their capital investments pre-determined by financial benchmarks (e.g., carriers typically tend to spend 13 per cent of their sales in capital expenditures). Taxes on equipment purchases negatively impact deployment.

For the case of the in the United States of America, Katz *et al.* (2012) and Katz and Callorda (2019) provided empirical evidence on the impact of taxation on communications investment. In their latest report, they assessed the impact of taxation on the level of telecommunication and cable industry investment in communications networks in a model that includes data on

28 Import Duty Calculator, retrieved from http://www.dutycalculator.com/popular-import-items/import-duty-and-taxes-for-network-equipment/.
29 See Bierbaum [et al] (2011).

all states, plus a number of state-specific case studies (Florida, Georgia, Illinois, Kentucky, Oklahoma, Tennessee, and Texas). According to the econometric models developed, a decrease of 1 percentage point in the average weighted state and local sales tax rate affecting initial equipment purchases (from 4.58% to 3.58%) would increase investment by 1.97 per cent over the current levels. By relying on input-output analysis, the effects that investment increases resulting from tax reductions can have in terms of economic contribution were also estimated (GDP growth and cumulative output driven by broadband construction).

Beyond the magnitude of the imposed rates, taxation can create further distortions that can have a negative incidence in operators. Katz (2015) describes the distortion that taxation can create within the digital ecosystem. The distortive effect of taxes in the digital eco-system was identified at three levels: 1) Potential disparity in tax burdens imposed on telecommunication operators when compared to other operators of the digital eco-system; 2) Taxation asymmetry among global players in the digital sector; and 3) In country taxation asymmetry between the telecommunication sector and other providers of other goods and services. In that respect, governments should examine these asymmetries to determine whether they are a source of distortion. Furthermore, considering the significant indirect impact of digital platforms (such as new business creation, and transaction efficiencies), governments should examine the issue of taxation of digital players in a careful manner.

A.1.1.6 Sector specific taxation and sector sustainability

In developing fiscal policies, governments need to consider the trade-offs between revenue generation and the potential negative impact on the development of the digital sector. As the evidence regarding the economic impact of digital industries continues to grow, the argument to reduce potential distortions emerging from over-taxation of the sector is gaining ground. Particularly, high fiscal pressures over the telecommunication sector may compromise the sector sustainability, in a context of reducing revenues and increasing investment needed to deploy last generation networks.

The sector is already subject of an important fiscal pressure, although some governments may still perceive taxing ICTs as an opportunity to increase revenue collection for national treasuries. To mention a specific example, Katz *et al.* (2017) studied for the Latin American countries the benefits and returns from their telecommunication operations. Taking as a reference the figures from 2014, nearly 43 per cent of the value added generated by the sector was invested, while nearly a significant amount of the value added was destined to the government treasury through several channels: profit and social taxes (20%), special contributions and taxes (13%), custom fees for equipment imports (5.6%) and spectrum payments (5.8%). These amounts exclude consumer related taxes (of all total payments made by the consumers, 33 per cent is transferred to the government). The comparison with other industries reviewed in the study developed by Katz *et al.* (2017) yielded interesting results. In Latin America, the telecommunications were identified as the economic sector with the larger fiscal pressure (51 per cent over the average of all sectors). For instance, similar sectors such as energy or other public services face a fiscal pressure 11 per cent lower than telecommunication sector. Other sectors, such as transport, face a fiscal pressure 39 per cent below telecommunications. The large amounts of taxes imposed can have an incidence on the long-term sustainability of investment and service quality improvements.

A.1.1.7 Spectrum management and service adoption

Mobile operators require access to sufficient spectrum to be able to deliver quality and affordable services to the consumers. Thus, effective spectrum management plays a key role for this purpose. In that respect, the quantity of spectrum allocated, the harmonization of this resource, the design of the auctions (and the determination of base prices), plus a flexible approach -for instance, in terms of technological neutrality or allowing spectrum trading- can have an important impact on market outcome, and as a result, on adoption levels and consumer surplus. In sum, spectrum management is central to the quality and affordability of mobile broadband services. However, sometimes governments choose to mandate certain band or technological decisions -limiting flexibility-, or to prioritize high prices being paid to access spectrum, which may condition medium- and long-term market outcomes. Empirical evidence tends to support the relevance of spectrum management:

- Zaber and Sirbu (2012) developed an econometric analysis over a multi-country panel dataset and were able to show that spectrum management policies had a significant influence on the evolution of 3G penetration across countries. Countries that mandated a specific frequency band for 3G saw faster diffusion, but in the long run those countries experienced a slower growth rate. However, estimations found that 3G diffusion was not significantly affected by the choice of auctions vs. alternative licence award processes.
- Bahia and Castells (2019) studied the impact of spectrum prices on consumers. They developed several econometric models designed to assess the impact of spectrum pricing on a broad range of consumer outcomes, by considering a sample of both developed and developing countries. Their sample was based on the spectrum costs of 229 operators in 64 countries (covering 30 developing and 34 developed countries). Their results show significant evidence to suggest a causal link between high spectrum prices, and certain other spectrum management decisions, and negative consumer outcomes. In particular, they found evidence that higher spectrum prices may have driven higher voice and data prices in developing countries, although Bahia and Castells state that evidence for most advanced economies was inconclusive.
- Kuroda and Forero (2017) studied the impact of spectrum policies for a sample of 47 OECD countries between 2000 and 2008. They found that when spectrum allocation auctions are designed to raise public revenues, the consumer surplus tends to be reduced.
- Hazlett and Muñoz (2009) performed an empirical analysis by relying in a sample of 28 countries for the period 1999-2003. They found evidence that the amount of spectrum and the degree of market competitiveness are key drivers for retail market outcomes, stating that auction rules that focus on revenue extraction may conflict with the goal of maximizing social welfare.

However, it must be said that not all the empirical research carried out arrived at the same conclusion. To mention a specific example, Park *et al.* (2011), for a sample of 21 OECD countries, were unable to find evidence of the impact of spectrum fees on consumer prices. Similarly, Bauer (2003) for a sample of 18 countries found no relationship between spectrum fees and voice prices. In any case, the studies carried out by both Park *et al.* (2011) and Bauer (2003) had a methodological disadvantage, as they relied on cross-section samples rather than data panels, a particularity that may be affecting their results.

A.1.1.8 Spectrum management and innovation

To encourage substantial investment and innovation in mobile services, it is important to have a transparent, long-term plan that includes a strategy for making sufficient amounts of spectrum available. Spectrum management, its pricing, and the imposition of associated obligations can have a significant impact on investment and innovation. This is generally supported by the empirical evidence reviewed:

- Bahia and Castells (2019) studied the impact of spectrum prices on several market outcomes, including coverage levels and data speeds. They conclude that high spectrum costs restrict the financial ability for network investment. In particular, they found strong evidence that higher spectrum prices have a negative impact on mobile coverage in the short and medium terms, in both developed and developing countries. They also found evidence that high spectrum prices have a long-term negative impact on network quality, including download/upload speeds and latencies.
- Kim *et al.* (2011) examined the effect of regulated MVNO entry on the investment behaviour of those owning networks, using firm-level data from 58 operators in 21 OECD countries during 2000-2008, with results suggesting that mandated provision of spectrum for MVNO was related to a lower investment intensity of network operators, while voluntary access provisions had no effect.

Again, to share an opposite view, for a sample of 21 OECD countries, Park *et al.* (2011) were unable to find evidence of the impact of spectrum fees on investment levels.

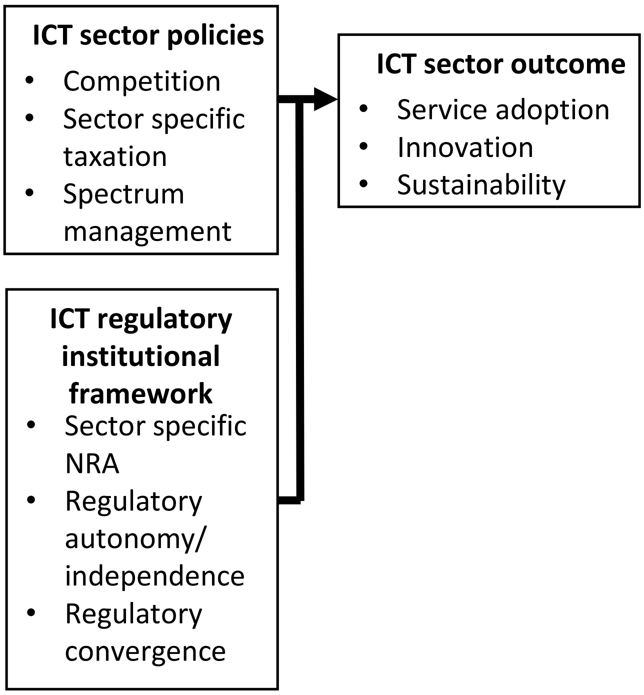
A.1.1.9 Spectrum management and sector sustainability

Suitable spectrum policies are also relevant for the sustainability of the mobile operators. When spectrum auctions are promoted intending to maximize revenues, usually the operator constrains future deployments due to the strain in its financial capabilities. This situation harms consumer welfare, and the economic sustainability of the enterprises. Mobile operators currently spend important amounts of money in spectrum fees and permits. For instance, for the case of Latin America, Katz *et al.* (2017) found that in 2014 nearly 43 per cent of the value added generated by the sector was invested, while 5.8 per cent of the value added was destined to the government through spectrum payments. The amounts paid for spectrum represented a 9 per cent of the overall telecommunication CAPEX. In sum, spectrum management should be flexible and balanced in order to maximize social welfare and do not risk sustainability of investments.

A.1.2 ICT regulatory institutional framework and ICT sector outcome

Research evidence has so far been compiled in support of the multiple causal relationships linking ICT sector policies to market outcomes. In addition to the specific policies reviewed above, ICT sector outcome is also conditioned by the ICT regulatory institutional framework. Through its monitoring and enforcement capability, the regulatory institutional framework intermediates the causality between policies and market outcomes. While there are multiple dimensions that characterize an ICT regulatory framework, three are critical: (i) whether the ICT sector has a specific regulatory agency rather than relying on generic instances (this feature is correlated with technical capability), (ii) relative autonomy of the regulatory agency with respect to industry players and the State, and (iii) the scope of the regulatory agency in terms of multiple dimensions of the digital ecosystem (such as digital media, Internet platforms, and digital equipment) (Figure A.8).

Figure A.8: ICT regulatory / institutional framework and sectoral outcomes



Source: ITU

The research literature has provided vast evidence regarding the impact of the institutional framework on ICT service adoption and sector economic performance. For example, regulatory autonomy has been found to have a positive impact on wireless prices and penetration (Wallsten, 2001, Gutierrez, 2003), while improved institutional framework (e.g., independent NRA, lower corruption, contract enforcement) leads to better performance (Maiorano *et al*., 2007; Waverman *et al*., 2007). In the case of wireless, the policy framework was found to have a mediating impact on the diffusion and pricing of services. For example, certain specific policies (competition and number portability), when combined with regulatory autonomy have a positive impact on wireless prices and penetration, while number portability has a negative impact on prices (Maiorano *et al*., 2007; Grzybowski, 2005).

- The above-mentioned study performed by Wallsten (2001) undertook an econometric analysis of the effects of telecommunication reforms in Africa and Latin America from 1984 through 1997. The study found a significant role for separate ICT regulators in explaining sector performance.
- Gutierrez (2003) examined the effect of reform on telecommunication performance using a regulatory index and panel data techniques to test how regulatory governance affected sector performance. The sample included 22 countries of Latin America. The study found that a better regulatory framework will have a positive impact through greater network deployment.
- Waverman *et al*. (2006) attempted to determine the effects of public ownership and regulatory agency independence on regulatory outcomes in European Union telecommunications. They estimated the cost of terminating a call on the incumbent network as a function of density, government ownership, regulatory independence, and experience of the regulator. The key findings are that public ownership of the incumbent positively affect incumbent interconnection rates, but that this effect is mitigated by the presence of institutional features enhancing regulatory independence.
- Maiorano *et al*. (2007) studied the relationship between regulation and performance in the mobile telecommunication sector. In this study the authors try to separate the impact of regulation from the potential indirect effects due to country institutions. The information is

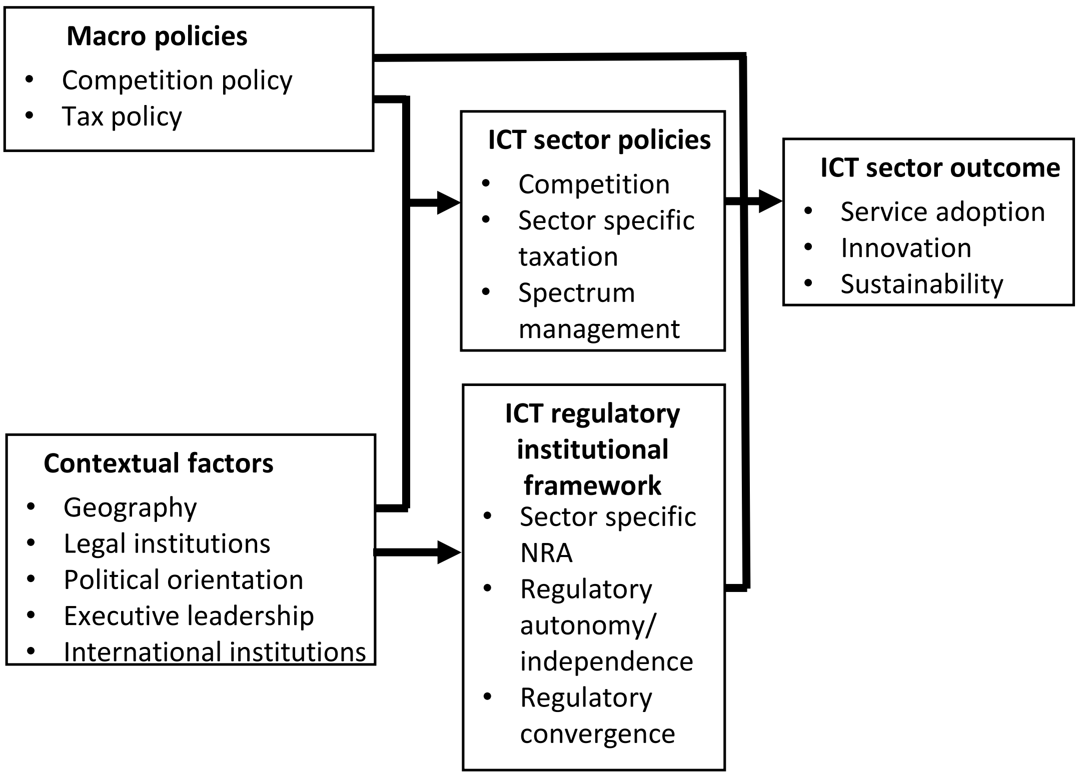
shown as a panel of 30 low and middle-income countries over 1990-2004. Some evidence showed that the existence of an autonomous infrastructure industry regulator increases penetration rates for mobile telecommunications in developing countries; on the other hand, neither the existence of a sector law nor the funding of the regulator through licence fees had any apparent statistically significant impact on mobile penetration. They also conclude that the policy framework has an impact on the diffusion and pricing of wireless services. An autonomous regulatory agency has an impact on prices and penetration. On the other hand, a sector law or funding of the regulatory agency through licence fees do not have an impact on wireless adoption.

- Katz (2020) studied how institutional and regulatory maturity impact the growth of the digital ecosystem, relying on a panel data from 139 countries between 2007 and 2018. The author used as dependent variable a Digitization Index, and as explanatory variables he included the ITU Regulatory Tracker variables, that attributes score to the regulatory authority, mandate, regime, and framework for each country. The author found that regulatory and institutional maturity in the ICT arena do indeed make a significant difference in driving the growth of digitization.

A.1.3 The impact of macro policies and contextual factors

Some of the policies reviewed above are not necessarily specific to the ICT sector but are influenced by macro policies and multiple contextual factors. This section analyses the specific role of macro policies and contextual factors as described in Figure A.9.

Figure A.9: Macro and contextual factors impact on ICT framework and outcomes



Source: ITU

A.1.3.1 The impact of macro policies on sector specific policies

Competition in the ICT sector should be understood within the context of general competition law. Among the most studied concepts in ICT competition that have been defined within the broader policy and legal domain, include the following:

- Monopoly and antitrust
- Market dominance
- Market concentration
- Significant market power

Other macro policies have a direct impact on sector outcome. For example, overall tax policy such as the VAT or sales tax, and import duties. The first one impacts the price of service acquisition, therefore affecting affordability. The second impacts the level of equipment purchasing (if imported). Both general taxes can undergo sector specific exemptions.

A.1.3.2 Contextual factors and ICT sector policies

In addition, ICT sector policies and the design of its institutional framework are not formulated in a vacuum. They are influenced by a number of contextual factors. In particular, the international diffusion of regulatory models may be driven by specific factors.

Since the 1980s, at an international level, the convergence of ICT policies has been guided by a process of diffusion of the frameworks and models developed initially in mature countries. Through this process, public policy implementation tends to follow a predetermined path of imitation determined by political, cultural, and local geopolitical parameters as well as by 'herd behaviour.' the diffusion of regulatory models is not necessarily guided by random social interactions. Indeed, policy diffusion can be a much more deterministic process following three mechanisms.

The first one is the so-called geographic proximity effect, whereby the diffusion of public policies is predetermined by the similarity of the situations and challenges of neighbouring countries. If Country X faces challenges like those challenges of neighbouring Country Y, it is highly likely that the government of Country X will adopt policies previously implemented by Country Y. This behaviour results from the geographical proximity that allows public officials to interact frequently, a process known as 'copying your neighbour'.

The second regulatory model diffusion mechanism is called the 'lateral diffusion mechanism' whereby the imitation of models and policy frameworks is the result of several countries either sharing the same cultural background or operating within the same social and economic context. The difference between the geographical proximity and the lateral diffusion mechanisms is that in the second case, both countries do not necessarily have to be neighbours so long as they have similar social and economic and political systems.

The third regulatory and policy diffusion mechanism is the so-called hierarchical diffusion effect. As its name indicates, central countries initially introduce public policies that are then adopted by peripheral nations that follow the lead of more mature nations. The need to reduce uncertainty in the policy-making process (which results from imitating a leading country), the imperative to reduce information costs (policy imitation reduces the need to analyse the specificities of the adopting country), and the legitimization provided by the opinion leaders of the country that originally espoused the model may all guide the herding process.[30] As such, the selection of a specific regulatory model or policy framework is determined not by the available information and analysis of the situation, but instead by a process of imitation. In this sense, some countries might influence the behaviour and cognitive framework of other nations that are adopting a new public policy. When these signals and changes in policy lead to convergence of an important number of countries, then herd behaviour can be witnessed. In terms of the transfer of regulatory and policy frameworks, herding exhibits several peculiar effects. For one, numerous countries undertake similar policy decisions (e.g., the privatization of the dominant telecommunication operator) within a very short period of time. Underpinning this process is a spreading mechanism that facilitates the diffusion of the model. Secondly, incentives to imitative behaviour is also seen. For example, a certain policy may have greater value as more countries choose to adopt it. In other words, one country may think, "*if all these countries have privatized, we can't go wrong by imitating them*." This rationale is known as the stimulus of uncertainty reduction. Herding also enhances the reputation of the policy-makers of the country adopting the new policy ("*by privatizing the operator, we behave in the same way as all of these other important countries who have done so before*"). Finally, herding reduces the costs of obtaining the information and analysis required to make an informed public policy decision, (possibly labelled as the value of the 'benchmark'). Certain neo-institutional sociologists (Jepperson and Meyer, 1991; Meyer *et al.*, 1997) have studied the process by which policy-makers imitate their counterparts in other countries to reduce research costs from legitimization.

In addition, other contextual factors may have an incidence of ICT sector policies and institutional design:

- International institutions: International affiliations are essential as they make reference to the role of regional regulatory spaces. In this regard, public policies and regulatory mechanisms are diffused through institutional networks that facilitate the transfer of models. The institutions involved in the diffusion of public policies and regulatory frameworks within the ICT arena fall into one of three categories. First and foremost, transnational institutions (such as the European Commission, OECD, the World Bank, the United Nations, Organization of American States, CAF, and Inter-American Development Bank) play a key role in the transmission and promotion of regulatory framework and public policy recommendations.[31] Second, international organizations must also be considered, both from inside the ICT sector (Regulatel, Berec) and from outside the sector (e.g.: The Commonwealth). This way, the institutional factor (or the 'regional regulation spaces') plays an important role in the promotion of policy convergence. Katz (2014) examined, for the Latin American region, the role that existing policy institutions and regulatory coordination mechanisms play in innovation and development of the ICT sector, focusing on the advantages of coordinating 'regional regulatory spaces', in order to harmonize ICT regulatory frameworks and public policies.
- Policy entrepreneurs: public policy 'entrepreneurs' are accounted for (consultants, experts, nongovernmental organizations) and should be viewed as promoters of 'better practices' and 'benchmarks'.
- Legal institutions: there is several literature linking the role of legal institutions and economic performance (see for instance Dawson, 1998; Acemoglu *et al.*, 2001; Rodrik *et al.*, 2004; among many others), with empirical analysis suggesting a positive influence of sound institutions on development through the promotion of the investment channel. As for investment decisions, several authors argue about the importance of protecting property

[30] According to Levi-Faur and Jordana (2005), "Most cases of diffusion are based not on rational learning but on a myriad of mechanisms in which the rational component, if any, remains small".

[31] The regulatory entities for telecommunications in Brazil and Argentina are designed according to the norms of better practices of the World Bank.

rights to avoid expropriation risks (Besley, 1995; Dawson, 1998; Acemoglu *et al.*, 2001; Henisz and Zelner, 2001; Rodrik *et al.*, 2004; Andonova and Díaz-Serrano, 2009). Similarly, an independent justice is particularly relevant, as it can help to ensure property rights (Olson, 1993). Beyond the specific expropriation risk, investors usually present specific concerns to arbitrary or capricious policy changes. In this sense, trust and credibility is key to create a propitious environment for investment, as well as institutional efficiency to defend investors complaints, such as dispute resolution or the possibility to challenge the introduction of regulations that may be of dubious legality to those concerned. As for the specific evidence for the ICT sector, Henisz and Zelner (2001) analysed differences in the levels of checks and balances on executive discretion created by variation in political structures and party systems and how it affects service penetration for a sample of 147 countries during period 1960-1994. They used as dependent variable the number of telephone lines every 10.000 inhabitants, measuring the effects of credibility of policy regimes. In turn, Esfahani and Rami ́ rez (2003) analysed the impact of institutional variables in the growth rate of telephones per capita for a sample of 75 countries for the period 1965-1995. Andonova (2006) and Andonova and Díaz-Serrano, 2009 studied the determinants of Internet and mobile phone penetration, considering a series of institutional variables, finding that Internet access is shown to depend strongly on the country's institutional setting because fixed-line Internet investment is characterized by a high risk of state expropriation, but on the other hand, mobile phone networks, were found to be less dependent on institutional characteristics.

- Political orientation. The ideological sign of the governments may also have an incidence on the general policy approach. Typically, left-wing governments exhibit larger levels of market intervention, while, on the contrary, right-wing administrations tend to prioritize the development of free markets through lower levels of policy intervention regulation and taxation.

A.1.4 Macroeconomic outcomes

At the tail end of the causality model, ICT sector market outcomes have an impact on the macroeconomic context. In other words, the higher the performance of the ICT sector in terms of service adoption and service quality, the higher the impact on the GDP the growth of the digital economy, and the increase in average household income.

A.1.4.1 The impact of ICT service adoption on GDP

Studies on the economic impact of digital technologies have been produced for the past two decades confirming, to a large extent, that telecommunications, and broadband in particular, have an impact on economic growth (Hardy, 1980; Karner and Onyeji, 2007; Jensen, 2007; Katz *et al.*, 2008; Fornefeld *et al.*, 2008; Katz and Suter, 2009; Koutroumpis, 2009; Czernich *et al.*, 2011; Katz, 2011; Katz *et al.*, 2012; Bertschek *et al.*, 2013; Mack and Faggian, 2013; Katz and Callorda, 2018; Rohman and Bohlin, 2012; Arvin and Pradhan, 2014). Under normal conditions, digitization usually translates into economic gains as a result of productivity improvements due to the adoption of more efficient business processes (e.g., marketing, inventory optimization, and streamlining of supply chains); in accelerated innovation by introducing new consumer applications and services (e.g., new forms of commerce and financial intermediation); and in more efficient functional deployment of enterprises by maximizing their reach to labour pools, access to raw materials, and consumers (e.g., outsourcing of services, virtual call centres).

A.1.4.2 The impact of ICT service quality on GDP

The study of the economic impact of ICT service quality has focused primarily on the impact of broadband speed on GDP. The research on the impact of increasing fixed broadband speed, first and foremost, has focused on GDP growth. This research generally concludes that faster Internet access has a positive impact on GDP growth.

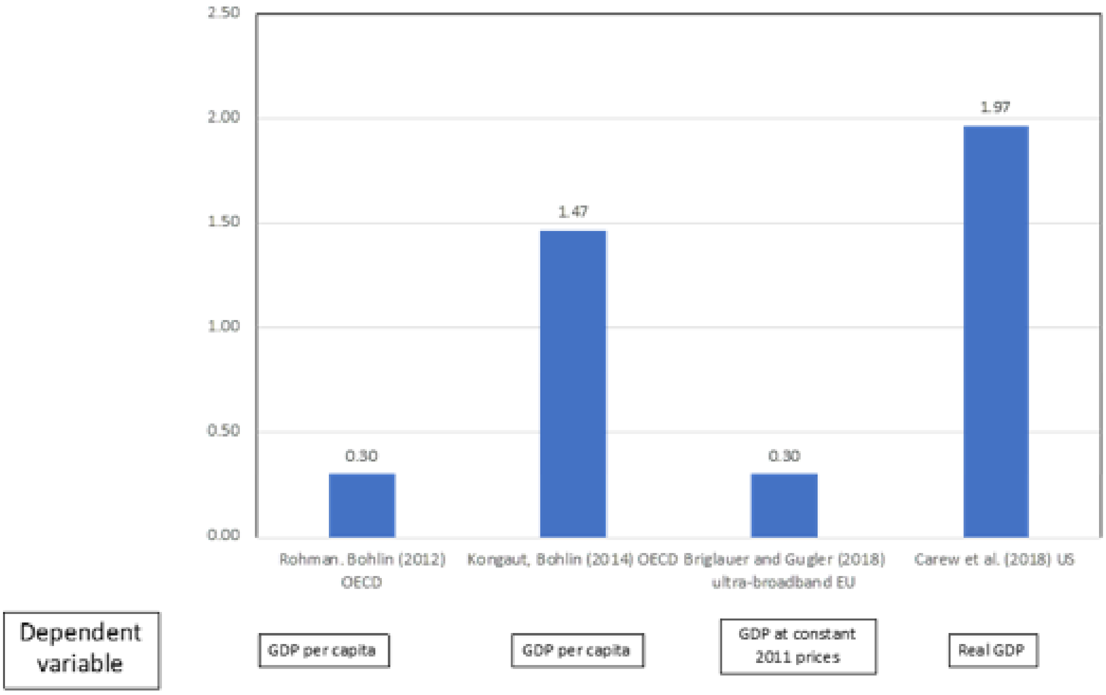
Two types of effects explain this causal relationship. First, faster broadband contributes to an improvement in productivity resulting from the adoption of more efficient business processes. For example, improved marketing of excess inventories and optimization of the supply chain are two of the effects 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 doubling the speed yielded a 0.3 per cent increase in GDP. Following on this study, Kongaut and Bohlin (2014) used a similar approach but differentiate 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 0.147 per cent for a general sample of countries, 0.1 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 European Union 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. That said, these results are driven from ordinary least square models. A two-stage least square regression testing the impact of ultrafast broadband penetration found a small (0.003) but significant effect over and above the effects of basic broadband on 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 100 per cent increase yields 1.37 per cent increase in real GDP.

As indicate in Figure A.10, while all studies conclude that broadband speed has an impact on GDP, the range of contribution varies. Some of the difference is explained by the 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, part of the difference in effects can be explained by the variance in average broadband download speed at the time of the study: for example, when Rohman and Bohlin (2012) conducted their study, average broadband download speed was 8.3 Mbit/s.

Figure A.10: Studies measuring the GDP impact on broadband speeds (impact of 100% increase in speed on GDP) (%)



Source: Various sources, Compiled by Telecom Advisory Services

A.1.4.3 The impact of ICT service quality on other metrics of macroeconomic performance

Broadband speed and household income

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 those are not linear and continuous, but nonlinear and stepwise. Furthermore, it was found that the impact of lower speed is greater in three large emerging countries (Brazil, China, and India) and for higher speeds, it is greater in OECD countries. It was also found that for the same increase in upgrade in speeds (0.5 Mbit/s to 4 Mbit/s), the income effect is bigger in OECD countries than in Brazil, China, and India (USD 322 per month vs USD 46 per month). On the other hand, Ford (2018) analysed data of the United States of America and found no economic payoff from a 15 Mbit/s speed difference.

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 industries: 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. Cariolle *et al.* (2017) studied firms in 62 countries, using World Bank data, and detected a large impact of broadband speed on average annual sales and sales per worker.

Broadband speed and job creation

Research on the impact of broadband speed on employment, which takes place through firm relocation and start-up incubation, is fairly conclusive. Generally, research in this area has been focused on the United States of America, although one study relied on French data. 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 smaller 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. As 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 of America was done by Hasbi (2017), analysing panel data on 36 000 municipalities in France between 2010 and 2015. Hasbi found that deployment of high-speed broadband (> 30 Mbit/s) increases company relocation and start-up development in the non-agricultural sector. These two effects yield a positive contribution to the decline of unemployment.

A.1.4.4 The impact of ICT sector performance on the growth of the digital economy.

Beyond the spillover effects over the overall economy, digitization is expected to have a specific positive impact on the ICT-sector outcome. This may be materialized through higher software and hardware production, more platforms and contents developed, bigger penetration for e-commerce, and the like.

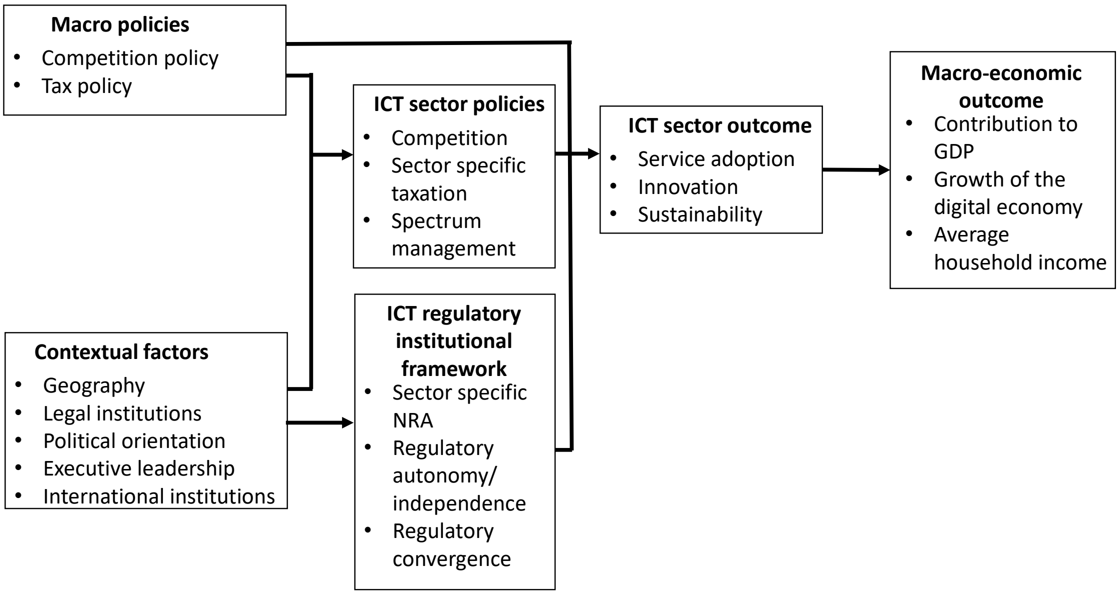
A.1.4.5 The impact of ICT sector performance on average household income

The aggregate economic effect of ICT developments is expected to yield increases in household income. Although empirical research is scarcer than that for the GDP impact, Katz and Callorda (2013) were able to find evidence of the socioeconomic impact of broadband deployment in Ecuador. They built a structural model based on four equations: a production function (for the aggregate economy), and three additional functions for the broadband market: demand, supply and product. Their results point at a positive contribution of broadband to the Ecuador GDP between 2008 and 2012, which in turn will impact on individual incomes, finding evidence of an annual increase of 3.67 per cent in labour income attributable to broadband.

A.1.5 Overall causality model

We have reviewed a large portion of the research evidence in support of each of the causality links in the overall model framework. The combination of all the elements of the causal framework results in the following flow diagram (Figure A.11).

Figure A.11: Overall model by considering causality flows



Source: ITU

To reiterate the level of complexity, the principal causal relationship between ICT sector policies and market outcome is predicated on multiple links whereby each of the four independent variables (competition model, sector specific taxation, spectrum management, other regulations) affect each of the three dependent variables (service adoption, innovation, and sector sustainability. The impact of ICT sector policies on market outcomes is mediated by the ICT regulatory institutional framework, which conditions policy effectiveness. Furthermore, ICT sector policies are developed influenced by non-sector specific macro policies (national competition policy models, tax policy) and contextual factors (such as the country's position in the policy diffusion process, legal institutions, and the role of influencing parties). Finally, the ICT market outcome has an impact on the macro-economic outcome in terms of growth of the GDP, growth of the digital economy and other economic variables such as average household income.

That said, this model is not static. As some of the research reviewed above already indicates, independent variables may interact among themselves to drive different effects (such is the case of the competition model and spectrum model). In addition, some of the outcome variables might also condition each other creating 'second order' effects.

A.2 System dynamics influencing the causal framework

The concept of systems dynamics is used to frame the behaviour of complex systems that is built upon mutual causation among variables and time delay relationships among its components. While not specifically applying the methodology to the causality model, some of the dynamics addressed in systems dynamics are quite applicable to the causal framework, in terms of time-delayed relationships and interlocking variables. Some specific research has formalized the dynamic relationship among variables.

A.2.1 Trade-offs in policy formulation

Several trade-offs may take place in the process of policy formulation. A typical example is those competition policies which prioritize short-term static efficiencies, but on the contrary, may compromise long term dynamic efficiencies (this issue is further addressed below). Therefore, public authorities should be aware of all these cross effects that take place because of regulatory decisions.

A similar effect happens in the above reviewed taxation and spectrum pricing literature. Authorities must choose between maximizing short term revenues or to promote approaches looking to enhance investments. The dynamic long-term perspective is the one that usually translates into larger investment and innovation, which in turn induces larger social welfare.

A.2.2 Interrelationship among outcome variables

Some ICT market outcome variables are expected to be correlated. For instance, that is the case of prices and investment levels. In the short run, higher prices may yield larger revenues, which in turn should promote investments. However, in the long run, larger investments may produce efficiencies that can translated into price reductions. Genakos *et al.* (2015) studied these effects for a panel of OECD countries for the period 2002-2014. Their results point at a trade-off effect while evaluating mergers of mobile operators. A merger that reduces the number of operators from 4 to 3 will result in an increase of prices of 16.3 per cent, combined by an increase in investment of 19.3 per cent.

Highlighting the complexity of the analysis, Houngbonon (2015) studied the impact of market consolidation on prices in the Austria market, after a merger between the third and fourth operator. Using investment as an intermediate variable, the study provides evidence that migrating from four to three operators allows an increase in technological investment, which in turn reduces the production costs for mobile telecommunications. This dynamic efficiency allows, in turn, to reduce end-consumer prices for data services.

This evidence suggests that the non-linear link between competition and investment should be studied with a dynamic focus, assuming that the latter is affected by the regulatory framework. Ultimately, considering that investment is what allows innovation in new technologies, an increase in investment will spur innovation, which in turn will be associated with an increase in consumer surplus. As an example, in the United States a 27 per cent increase in consumer surplus was estimated between 2006 and 2020 after the migration from commuted Internet access to broadband connectivity. In Brazil, a total surplus was estimated in the order of USD 7 000 million for year 2009, representing a 22 per cent increase for consumer surplus[32].

A.2.3 Time-delayed relationships

Regardless of the model structure formalized above, it is important to stipulate that the causality effect operates under certain timing conditions, through multiple steps that link policies to market outcomes. For example, a change in policy should be interpreted as a signal that might trigger a shift in the strategy of sector players. After the announcement of a policy change, some time will be needed for investors to completely assess those reforms and to introduce strategic changes. In addition, even as the change in strategy takes place, that might not immediately translate in changes in firm behaviour. This means that policy changes may not result in an immediate impact on sector performance. This particularity has been studied in the context of network investments.

[32] See http://www.teleadvs.com/wp-content/uploads/LCR2167_Acelerando-la-revdigital_CEPAL-chapter.pdf.

To mention an example, Katz and Callorda (2019) modelized for a sample of US states the impact of eliminating the sales tax on network equipment, splitting the economic effects across a period of two years: increase in investment of USD 3.881 billion over one year and USD 9.920 billion cumulative over two years, with differentiated impact on GDP and employment over the first and second year of analysis.

This particularity is taken into account in the empirical model, by considering the possibility of adding time-lags to some key explanatory variables (this issue is addressed in detail in section 7.1). The magnitude of that lag between policy reforms and changes in market outcomes may depend on a series of factors. For instance, the possible existence of market constraints and business practices that can limit the transition must be taken into account.

A.3 Transborder effects

Another complexity dimension in the causal framework resides on the mutual influence o national models. As in the case of contextual variables, national ICT policies and market outcomes do not operate in isolated environments. Outcomes can be affected if policies are adopted by other countries. We will provide two examples of these situations.

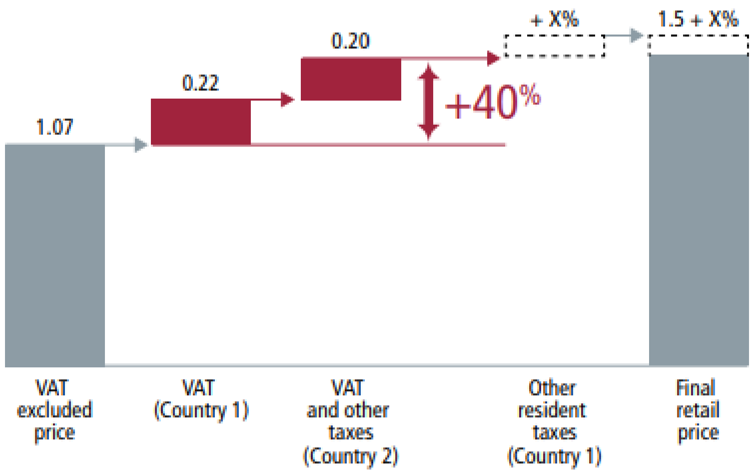
A.3.1 The impact of double taxation on cross-border digital services

Double taxation refers to certain taxes paid twice on the same source of income. Usually, double taxation occurs in international operations when the same source of value is taxed in two different countries. The main effect generated by double taxation is that it inflates retail

prices, becoming inefficiently high. As some digital services have a cross-border nature, this distortion can affect the development of ICTs.

A typical example is that of international roaming. Double taxation increases retail prices affecting industry and mobile users, as well as government revenues (GSMA, 2012). Figure A.12 describes the double taxation effects on roaming prices.

Figure A.12: Double taxation effect on roaming prices



Source: GSMA (2012)

To avoid this problem, some countries have signed double taxation agreements, which usually consist in dividing the right of taxation between the contracting countries, to avoid differences, ensuring taxpayers' equal rights and security, and preventing evasion.

A.3.2 Distortions from different regulations affecting cross-border services

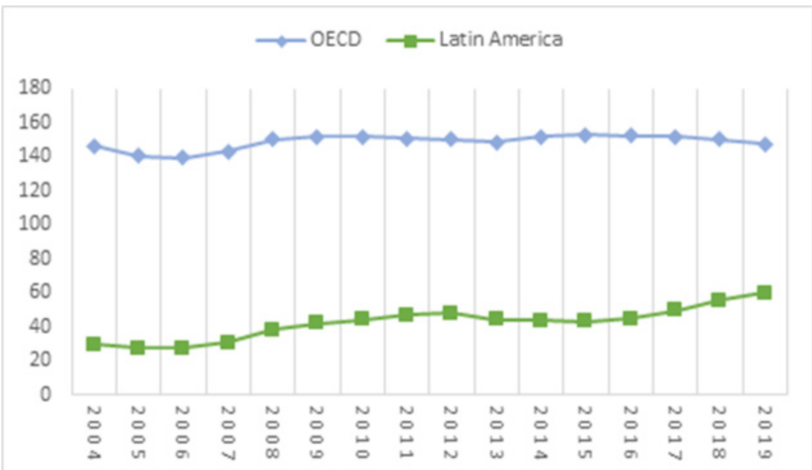
Taxation is not the only factor being affected by the cross-border nature of most digital services. The massification of Internet has enhanced the cross-border nature of ICTs, and currently users consume platforms developed and provided from aboard. When consumed in a different jurisdiction from that of its enactment, those platforms may not necessarily fulfill with all regulatory aspects required within the national boarders, potentially affecting privacy, data protection, intermediate responsibility criteria, and other norms. Thus, platforms when provided from aboard may be subject to a different set of rules tan those platforms developed within the borders. This particularity can generate distortions and asymmetries across competing actors within a same market.

A.4 Difference between advanced economies and developing countries

Some important differences can be expected between advanced and developing economies. In terms of regulatory practices, usually developing countries lag behind those advanced economies, and in many situations good practices are imitated as a result. That is to say, developing economies are usually followers in terms of regulatory practices. On the other hand, most advanced economies are generally known for having better institutional quality than emerging regions, a particularity that can affect investment decisions.

As for investment levels, usually more advanced countries invest bigger amounts than those with lower development level (see the case of OECD and Latin America in Figure A.13). This is explained in part due to more advanced regulations and sound institutions, and on the other hand, due to bigger income levels. The revenues that the telecommunication sector collect from advanced economies, as measured through the ARPU indicator, are much larger than those from developing countries, therefore the investment capacity is affected.

Figure A.13: CAPEX per capita in telecommunications



Note: CAPEX per capita at current USD prices (5-year average)

Source: ITU, Telecom Advisory Services analysis

As for the specific impact of certain policies and regulations, some of the reviewed studies were able to find significant differences between developing and developed countries. Just to mention a few examples, Garcia-Murillo (2005) showed that unbundling of incumbent infrastructure only results in a substantial improvement in broadband deployment for middle-income countries, but not for their high-income counterparts. In turn, Bahia and Castells (2019) studied the impact of spectrum prices on a broad range of consumer outcomes, by considering a sample of both developed and developing countries. Their results point at higher spectrum prices driving higher voice and data prices in developing countries, although the evidence for most advanced economies was inconclusive.

Similarly, the impact of ICT adoption on macroeconomic variables, such as GDP, can vary largely between developing and developed countries. This particularity is explained in Katz and Callorda (2018) and in Katz (2020), due to differences in return to scale and critical mass effects. On the one hand, the impact of ICT on economic output is maximized once the infrastructure reaches a certain threshold of critical mass associated to the levels of penetration. As long as developed countries have larger penetration levels, connectivity should yield a larger economic outcome. This was verified, for instance, by Roeller and Waverman (2001), by estimating a larger economic impact from wireline telecommunications for OECD than for non-OECD countries. Similarly, in Katz and Callorda (2018), fixed broadband penetration was found to exhibit a strong economic impact in high income countries but was non-significant in middle income and low-income economies. On the other hand, there may also be a different effect going through the opposite direction, that is the saturation and diminishing returns effect. In that sense, some have pointed out that beyond a certain adoption level, the contribution of a telecommunication technology to the economy tends to diminish. Therefore, a nonlinear relationship between ICT adoption and output is expected.

All in all, these different dynamics between developing and developed countries make worth a detailed assessment, for instance, by splitting the samples across country groups.

B. Countries included in the empirical analysis

Albania, Algeria, Angola, Argentina, Armenia, Australia, Austria, Azerbaijan, Bahamas, Bahrain, Bangladesh, Barbados, Belarus, Belgium, Belize, Benin, Bhutan, Bolivia, Bosnia and Herzegovina, Botswana, Brazil, Bulgaria, Burkina Faso, Burundi, Cabo Verde, Cambodia, Cameroon, Canada, Central African Republic, Chad, Chile, China, Comoros, Democratic Republic of the Congo, Costa Rica, Côte d'Ivoire, Croatia, Cyprus, Czech Republic, Denmark, Djibouti, Dominica, Dominican Republic, Ecuador, Egypt, El Salvador, Estonia, Ethiopia, Finland, France, Gambia, Georgia, Germany, Ghana, Greece, Grenada, Guinea-Bissau, Guyana, Honduras, Hong Kong SAR (China), Hungary, Iceland, India, Indonesia, Islamic Republic of Iran, Ireland, Italy, Jamaica, Japan, Jordan, Kazakhstan, Kenya, Kiribati, Korea, Kuwait, Kyrgyz Republic, Lao P.D.R., Latvia, Lesotho, Lithuania, Luxembourg, Madagascar, Malawi, Malaysia, Mali, Malta, Mauritania, Mauritius, Mexico, Moldova, Mongolia, Montenegro, Morocco, Namibia, Netherlands, New Zealand, Nigeria, Norway, Oman, Pakistan, Panama, Peru, Philippines, Poland, Portugal, Qatar, Romania, Russia, Rwanda, Samoa, São Tomé and Príncipe, Saudi Arabia, Senegal, Serbia, Singapore, Slovak Republic, Slovenia, South Africa, Spain, Sri Lanka, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Sudan, Suriname, Sweden, Switzerland, Thailand, Timor-Leste, Togo, Tonga, Trinidad and Tobago, Tunisia, Turkey, Uganda, Ukraine, United Arab

Emirates, United Kingdom, United States of America, Uruguay, Uzbekistan, Venezuela, Yemen, Zambia, Zimbabwe.

C. Variables for the empirical analysis

To perform the empirical analysis, the ITU ICT Regulatory Tracker pillars were relied on first and in the overall score to assess the incidence of the regulatory environment impacting investment decisions. The ICT Regulatory Tracker provides a useful tool for benchmarking and the identification of trends in ICT legal and regulatory frameworks. The ICT Regulatory Tracker is a composite index based on 50 indicators grouped into four pillars: regulatory authority, regulatory mandates, regulatory regime, and competition framework (see table C.1).

Table C.1: Pillars of the ITU ICT Regulatory Tracker

Pillar	Description
Regulatory authority	Index that measures the characteristics and the functioning features of the regulatory body and in the presence of a national competition authority. The index takes a maximum value of 20 (the minimum score is 6) and is built with data from 10 different indicators: separate telecom/ICT regulator, autonomy in decision-making, accountability, percentage of diversified funding, public consultations mandatory before decisions, enforcement power, sanctions or penalties imposed by regulator, dispute resolution mechanism, appeals to decisions, existence of competition authority.
Regulatory mandate	Refers to the entity in charge of regulating each area: QoS, licensing, interconnection rates and price regulation, spectrum, universal service access, broadcasting, Internet and IT. The index takes a maximum value of 22 (the minimum score is 6), and is built with data from 11 different indicators: entity in charge of quality of service obligations measures and service quality monitoring, licensing, interconnection rates and price regulation, radio frequency allocation and assignment, spectrum monitoring and enforcement, universal service/access, broadcasting (radio and TV transmission), broadcasting content, Internet content, IT, consumer issues.
Regulatory Regime	Refers to specific regulations in terms of licensing, interconnection, QoS, infrastructure sharing, access regulation, and number portability, among others. The index takes a maximum value of 30 (the minimum score is 8), and is built with data from 15 different indicators: types of licence, licence exempt, operators required to publish reference interconnection offer, interconnection prices made public, quality of service monitoring required, infrastructure sharing for mobile operators permitted, infrastructure sharing mandated, co-location/site sharing mandated, unbundled access to the local loop required, secondary spectrum trading allowed, band migration allowed, number portability required from fixed-line operators, number portability required from mobile operators, individual users allowed to use VoIP, national plan that involves broadband.

Table C.1: Pillars of the ITU ICT Regulatory Tracker (continued)

Pillar	Description
Competition framework	Based on the competition level for different market segments, regulatory definitions for SMP, and foreign participation /ownership. The index takes a maximum value of 28 (the minimum score is 8), and is built with data from 14 different indicators: Competition exists in local and long distance (domestic and international) fixed line services, IMT (3G, 4G, etc.) services, cable modem, DSL, fixed wireless broadband, leased lines, international gateways, status of the main fixed line operator (public, partially or fully private), legal concept of dominance or SMP, criteria used in determining dominance or SMP. Foreign participation/ownership in Facilities-based operators, spectrum-based operators, local service operators/long-distance service operators, international service operators, Internet service providers (ISPs), value-added service providers.

Source: ITU – ICT Regulatory Tracker, itu.int/go/tracker

As denoted in Table C.1, the different pillars of the ICT Regulatory Tracker can be interpreted as proxies for the sectoral institutions (regulatory authority), scope of the regulator (regulatory mandate), regulation quality (regulatory regime) and competitive environment (competition framework). The overall score is assumed to be a measure of sound regulatory and institutional environment.

However, the main disadvantage of exclusively relying on the Tracker scores is that they could miss details referred to the impact of specific regulations. Thus, in order to be more policy specific, additional empirical tests using selected policy indicators were performed. Some of the chosen variables are sub-indicators of the different pillars of the ICT Regulatory Tracker, and in other cases indicators were compiled from external sources. The complete list of variables is detailed in Table C.2.

Table C.2: Other variables for the empirical analysis

Variable	Description	Source
CAPEX	Investment in telecommunication services	ITU
CAPEX Mobile	Investment in mobile telecommunication services	GSMA
REVENUE	Revenue from telecommunication services	ITU
REVENUE Mobile	Revenue from mobile telecommunication services	GSMA
DEMAND	Mobile broadband unique subscriber penetration	GSMA
HHI Mobile	Herfindahl Hirschman Index of the mobile sector	GSMA
4G coverage	Percentage of population covered by a 4G network	GSMA
Cellular coverage	Percentage of population covered by a mobile-cellular network	ITU
Mobile broadband price	Data-only mobile broadband price for 1.5GB	ITU
Spectrum sharing allowed	Dummy variable that takes the value of 1 if active infrastructure sharing for mobile operators is permitted (e.g., MVNO)	ITU

Table C.2: Other variables for the empirical analysis (continued)

Variable	Description	Source
Convergent licences	Score taking values from 0 to 2 depending on the scope of the licences provided in the country. The score takes the lowest value when only service specific licences are issued, and the highest value in case of unified / global licences, general authorizations or simple notification.	ITU
No restriction to foreign operators	Dummy variable that takes the number of 1 if no restrictions are placed for foreign spectrum-based operators	ITU
Mobile number portability	Dummy variable that takes the number of 1 if number portability is required from mobile operators	ITU
SMP	Indicator taking values from 0 to 2 depending on the definition and scope of Significant Market Power	ITU
Mobile taxation	Tax rate for mobile cellular tariffs	ITU
Profit taxes	Profit tax as a percentage of commercial profits	World Bank
National broadband plan	Dummy variables that take the value of 1 if a national broadband plan has been implemented	ITU
National competition authority	Dummy variable that takes the value of 1 if the country has a national competition authority	ITU
Time to start a business	Time required to start a business (days)	World Bank
OECD (years)	Years from membership to OECD	OECD
WTO (years)	Years from membership to WTO	WTO
Urban population	Percentage of population living in urban areas	World Bank
GDP per capita	Gross Domestic Product per inhabitant in current USD	IMF

The data collection resulted in an unbalanced[33] panel composed by 145 economies during the period 2008-2019. Naturally, when missing observations on certain variables, some of the estimated regressions to be performed will not include the complete set of that particular country and/or years.

[33] It refers to the fact that some information is missing in the dataset. A panel is called to be unbalanced when at least one group from the cross-section dimension is not observed every period. Thus, if an unbalanced panel contains N cross-section groups and T periods, then the number of observations in the dataset is lower than N×T.

D. Empirical methodology

D.1 Model specification

Based on the literature review, a model that includes four main empirical equations was developed: (i) the regulatory and institutional context model linking framework conditions to telecommunication investment decisions; (ii) the increase in coverage model that links telecommunication investment decisions to their result in terms of network deployment; (iii) the price model, linking price evolution to network expansion, competitive intensity and taxation; and (iv) the telecommunication adoption equation which links adoption to investment outputs (i.e., coverage and prices).

D.1.1 The investment equation

The first equation intends to explain the determinants of telecommunication investment. As presented in the reviewed literature, CAPEX, that is to say the variable measuring capital expenditures of telecommunications operators, is expected to depend on three independent variables:

- the CAPEX of prior year given that investment is usually based in multi-year deployment plans;
- telecommunication sector revenues (*REVENUE,* to proxy financial capabilities for investment and market size) given that the revenues of telecommunications operators drive their capability to invest; and
- a vector *X* combining three variables: sector policies, institutional environment, and competition framework.

This equation is defined as follows:

$$\log(CAPEX_t) = \alpha + \beta\log(CAPEX_{t-1}) + \gamma\log(REVENUE_{t-1}) + \delta(X_t) + \varepsilon \qquad [1]$$

From an econometric perspective, there are three issues regarding endogeneity that need to be addressed in this investment equation. In the first place, the introduction of the lagged dependent variable as a regressor is expected to generate correlation with the fixed effects in the error term. This situation creates a "dynamic panel bias" (Nickell, 1981), as the reported correlation violates the necessary assumptions for consistency in Ordinary Least Squared (OLS) estimators.[34] As a result, it cannot be estimated through the usual fixed effects approach. We will follow alternative estimation strategies in order to ensure a consistent and unbiased estimation. In the second place, there may be a reverse causality link between revenue and investment. This is explained because, on the one hand, revenues provide the funding for investment, but on the other hand, investment is done in order to increase future revenues. Even if this identification concern is not significant (as investments are expected to translate into larger revenues only in the future), a cautious approach relies on the lagged revenue regressor rather than on the contemporaneous variable. Finally, as pointed out by the specialized literature, the contextual

[34] One of the required conditions for consistency in OLS is that regressors (z) are not correlated to the error term of the equation (that is to say, *COVARIANCE* (z, ε) = 0). In a dynamic panel with fixed effects and the lagged dependent variable as regressor, this assumption is violated. This can be verified through the following example. Consider a hypothetical dynamic relation: $y_{it} = \mu + \rho y_{it-1} + \varepsilon_{it}$ in which the error term meets the desired properties ($\varepsilon_{it} \sim iidN(0, \sigma^2)$). The fixed effects estimation approach consist in differentiation with respect to intra-group means: $y_{it} - \bar{y}_i = \rho[y_{it-1} - \bar{y}_i] + [\varepsilon_{it} - \bar{\varepsilon}_i]$. From the previous equation it seems clear that there is a correlation between the regressor and the error term (created by the averages $\bar{y}_i$ and $\bar{\varepsilon}_i$), resulting in *COVARIANCE* ($[y_{it-1} - \bar{y}_i], [\varepsilon_{it} - \bar{\varepsilon}_i]) \neq 0$. Therefore, the assumptions required by the conventional fixed effects OLS approach are not met, generating inconsistent estimations as a result.

variables defined in vector *X* may be endogenous to investment. For instance, Alesina *et al.* (2005) stipulates that regulation reforms may take place contemporaneously with idiosyncratic shocks to investment.

As for institutional variables, Mishra and Daly (2007) and Daude and Stein (2007) argue about a feedback effect in the sense that established investors can strongly demand better institutions, hence investment levels can be a factor explaining institutional quality, rather than the other way around (reverse causality). They also point out subjectivity bias or measurement errors in institutional indicators. To overcome these concerns, all regulatory and institutional variables entering the investment equation will be treated as endogenous.

D.1.2 The coverage equation

The population covered by telecommunication networks, a supply condition of service adoption, is driven by four variables:

- Capital investment of telecommunication operators, CAPEX, as estimated in the prior equation, is expected to drive future increase in broadband network coverage levels *(COVERAGE)*.
- In addition, coverage levels are expected to depend on past coverage improvements, even if those advances were specific to prior technologies. For instance, 4G deployments are surely facilitated by the presence of passive infrastructure previously deployed for 3G (towers, base stations, posts, ducts).
- Coverage may also depend in other local characteristics, typically the percentage of population living in urban areas (variable *URBAN*).
- Finally, coverage may also be determined by topographic conditions, such as presence of forests or hilly terrain.

Therefore, the second equation is modelled as follows:

$$\log(COVERAGE)_t = \Upsilon + \Phi\log(CAPEX_{t-i}) + \sum_{i=1}^{i=3} \nu_i \log(COVERAGE_{t-i}) + \lambda\log(URBAN)_t + \varepsilon \qquad [2]$$

Where $\Phi > 0$ is expected. Given that investment may take some time to be translated into coverage gains, *COVERAGE* is modelled in period *t* as a function of CAPEX in period *t-i*. The effective time-lag (that is to say, the chosen value of *i*) will be determined by considering the better goodness of fit for the model. The possibility to rely on previous technologies to account for previous coverage advances contributes to avoid using the lag of the dependent variable, thus preventing the "dynamic panel bias" as described above. As most of the topographic variables are time-invariant, those features will be captured by country-level fixed effects.

D.1.3 The price equation

Once the supply variable *COVERAGE* (network coverage) is estimated, price follows, a variable driving adoption through elasticity. End-user prices are assumed to depend on taxation applying to the services, as well as competition intensity. In addition, coverage improvements resulting from past investments contribute to reduce prices, as the supply curve shifts to the right. Coverage gains can also be interpreted as the result of technological improvements, which from a dynamic perspective, usually translate into lower prices. This brings the third equation:

$$\log(PRICES)_t = \Lambda + л(TAX_t) + \psi\log(COVERAGE_t) + г(COMPETITION_t) + \varepsilon \qquad [3]$$

As described above, $л > 0$ and $\Psi < 0$ is expected.

D.1.4 The adoption equation

In turn, the coverage advances and prices levels will be determinants for service adoption. Adoption is also expected to depend on income levels, which will be proxied through GDP per capita (in lags, to avoid reverse-causality concerns), and on the age structure of the population, as elder groups are expected to be less prone to adopt technology.

$$\log(DEMAND)_t = \Theta + \eta\log(PRICE_t) + \tau\log(COVERAGE_t) + \varsigma\log(GDPpc_{t-1}) + \sigma(AGE_t) + \varepsilon \quad [4]$$

Naturally, it is expected that higher prices should reduce demand (that is to say, $\eta < 0$), while on the other hand, coverage improvements make wider the market scope, impacting adoption levels positively ($\tau > 0$). Note that it is thus explicitly assumed that regulatory and institutional variables do not enter directly in the adoption equation, but only indirectly through prices and coverage, which, in turn, depend on CAPEX. This imposes some *a priori* structure on the model, which seems reasonable enough according to the causality flows reviewed in the research literature, and which helps carry out the identification strategy.

D.2 Empirical strategy

Two different strategies were conducted for the empirical estimation, depending on the data availability. Currently, the CAPEX series is available for the mobile segment, and for the overall aggregated telecommunication sector. Sadly, there are no reliable series of CAPEX for fixed broadband technologies. The ITU database reports capital investment for telecommunication services (overall), and also reports specific series for fixed telephony and mobile services. Even if the ITU started to report data for investment in fixed broadband, the series is still incomplete and very few observations are available. While trying to build a fixed Internet CAPEX series by subtracting mobile investment from the aggregated variable it was found that procedure to be inconsistent, as denoted by the presence of negative values. All in all, it was decided to go ahead with two CAPEX data series available: the aggregated and the mobile-specific capital investment.

While the first equation of our structural model -the investment equation- can be estimated for both aggregate and mobile segments, the remaining equations have to be defined as technology-specific. This is because the different dependent variables (Coverage, Prices and Penetration) are intrinsically related to specific technologies or services, and no reliable aggregation for fixed and mobile has been built for these variables as of yet. As a result, two distinct empirical strategies will have to be carried out: in the first place, the investment equation for the whole aggregated sector was estimated (fixed and mobile), focusing in assessing those environmental conditions not related to specific technologies or networks. Secondly, the complete structural model was estimated consisting of the four equations reported above for mobile broadband, focusing in contextual conditions applicable to wireless technologies.

E. Detailed estimation results

E.1 Estimation of investment equation for the combined fixed and mobile sectors

As stated above, the proposed investment equation should not be estimated through the fixed effects approach, as the introduction of the lagged dependent variable as regressor is expected to generate correlation with the fixed effects in the error term. This situation creates a "dynamic panel bias" (Nickell, 1981), as the reported correlation violates the necessary assumptions for consistency in Ordinary Least Squared estimators. The presence of short time-dimension in the panels, as in our sample, reinforces the presence of this situation (Roodman, 2009).[35]

In contrast to the conventional fixed effects approach, the estimator proposed by Arellano and Bond (1991) based on the Generalized Method of Moments (GMM), and augmented by Arellano and Bover (1995) into the System-GMM procedure is specifically designed for panels exhibiting short time-periods, larger cross-section dimensions one left-hand-side variable that is dynamic (that is to say, it depends on its own past realizations), fixed individual effects[36], and heteroskedasticity and autocorrelation within individuals but not across them (Roodman, 2009). These estimations use instruments derived from the own dataset, through lagged variables.[37] In addition to the instruments derived from the dataset, external instruments related to regulatory conditions can be added that may be useful to explain the endogenous variable and to facilitate identification.[38] In addition, policy and institutional contextual variables will be treated as endogenous, and will be instrumented with their own lagged values.

The empirical specification will be estimated following the two-step System-GMM method. However, in the two-step estimation, standard errors tend to be severely downward biased. To avoid that situation, the finite-sample correction will be computed proposed by Windmeijer (2005) to achieve robust estimates. As done in a similar model estimated by Kim *et al.* (2011), this includes a time-trend in all the estimates.

We start with a baseline model defined above, according to which the combined CAPEX depends on its own lag, on past revenues, and on the regulatory environment. Our first estimates focus on the introduction as regressors of the specific pillars of the ICT Regulatory Tracker. Each pillar was introduced individually (to avoid collinearity problems), and finally the overall score composed by the four pillars was introduced. Table E.1 summarizes the results.

35 In the conventional fixed-effects approach, the correlation generating the 'dynamic panel bias' is reduced only in the presence of large temporal (T) and short cross-section (N) dimensions, that is to say, when (N/T)´ 0. In our sample, the situation is the opposite: (T/N)´ 0. As a result, the fixed effects OLS estimation procedure is not appropriate in such circumstances.

36 The differencing procedure proposed by Arellano and Bond (1991) removes the country-fixed effects. Even if theoretically is possible to include time-invariant regressors in System-GMM (in the levels equation) Roodman (2009) does not recommend doing so, as are expected to cause within-groups transformations which may bias the estimation, especially for short time-dimension panels as in our sample.

37 As pointed out by Arellano and Bover (1995), a weakness of the original Arellano and Bond (1991) estimator is that lagged levels are often poor instruments for first differenced variables. For that reason, their proposed modification includes lagged levels as well as lagged differences.

38 External instruments added: spectrum sharing, mandated passive infrastructure sharing, band migration permitted, local loop unbundling required, licence exemption and convergent licences. All these instruments were introduced in lags.

Table E.1: Overall sector: two-step GMM estimation results

Investment equation - ICT Regulatory Tracker variables							
Dependent variable = Log(CAPEX)	[I]	[II]	[III]	[IV]	[V]	[VI]	[VII]
Log(CAPEX) (t-1)	0.596***	0.568***	0.660***	0.635***	0.652***	0.657***	0.644***
	[0.132]	[0.105]	[0.113]	[0.112]	[0.118]	[0.112]	[0.110]
Log(Revenue) (t-1)	0.287**	0.323***	0.215*	0.241**	0.228*	0.229**	0.230**
	[0.126]	[0.101]	[0.123]	[0.112]	[0.122]	[0.095]	[0.116]
Regulatory authority	0.057**						
	[0.024]						
Regulatory mandate		0.075**					
		[0.036]					
Regulatory regime			0.026*				
			[0.013]				
Competition framework				0.038**			
				[0.017]			
Regulatory authority & regulatory regime > median					0.054***		
					[0.022]		
Regulatory authority & regulatory regime < median					0.046**		
					[0.020]		

Table E.1: Overall sector: two-step GMM estimation results (continued)

Investment equation - ICT Regulatory Tracker variables							
Dependent variable = Log(CAPEX)	**[I]**	**[II]**	**[III]**	**[IV]**	**[V]**	**[VI]**	**[VII]**
Regulatory mandate & regulatory regime > median						0.054**	
						[0.026]	
Regulatory mandate & regulatory Regime < median						0.043	
						[0.031]	
ICT Regulatory Tracker (overall)							0.012**
							[0.005]
Arellano-Bond test AR(1) first differences	-1.77*	-1.75*	-1.76*	-1.76*	-1.78*	-1.75*	-1.76*
Arellano-Bond test AR(2) first differences	0.95	0.96	0.97	0.94	0.96	0.97	0.96
Over-identification test (Hansen J-test)	135.60	135.39	136.32	131.73	135.15	137.34	138.01
Time-trend	YES	YES	YES	YES	YES	YES	YES
Observations	826	826	826	826	826	826	826

*Notes: *p<10%, **p<5%, ***p<1%. Robust standard errors in brackets. Policy variables in columns [I] to [VII] treated as endogenous using the respective second lag as instruments.*

In all cases reported in Table E.1, the Hansen-J test does not reject the null hypothesis of exogeneity of instruments. Also, reported AR(2) tests suggest that the differenced residuals do not exhibit significant autocorrelation, which supports that the second lags of endogenous variables can be considered appropriate instruments.

Results reported in Table E.1 seem to be clear and robust regarding the incidence of a suitable regulatory environment on investment. The first estimate (column [I]) proves the relevance of the regulatory authority indicator. Therefore, having an own ICT regulator, with the desired characteristics, as well as a national competition authority contribute to create a suitable framework that spurs investment. The second column reports the positive and significant result for the regulatory mandate pillar, an index that takes higher values when the scope of the regulator is wider, which is the case, for instance, of a convergent regulator. The third column introduces the regulatory regime pillar, intended to measure the adoption on best regulatory practices according to ITU, proving to be significant at a 10 per cent level. In turn, the fourth column provides evidence of the significant role of a suitable competition framework to spur investment. Next, the coefficients were assessed for the regulatory authority and regulatory mandate variables splitting sample across those countries with a regulatory regime above and below the median. The results point at the complementarity between the different regulatory measures: the regulatory authority variable takes a lower coefficient for the sample of countries with regulation regime below the median, while regulatory mandate is no longer significant for this country group. Finally, the overall Regulatory Tracker, built upon the previous four pillars, was proven to exhibit a positive and statistically significant coefficient, at 5 per cent.

Next, further estimates were carried out splitting the respective regulatory variables across two groups: those of developing and developed countries.[39] The objective is to find out if regulation impact differs across the level of development of countries. Results, reported in Table E.2, show that there are not relevant differences across both country groups.

[39] Classification was done according to the United Nations M49 standard: https://www.itu.int/en/ITU-D/Statistics/Pages/definitions/regions.aspx.

Table E.2: Overall sector: two-step GMM estimation results

Investment equation - ICT Regulatory Tracker variables (by development)					
Dependent variable = Log(CAPEX)	**[I]**	**[II]**	**[III]**	**[IV]**	**[V]**
Log(CAPEX) (t-1)	0.606***	0.605***	0.665***	0.640***	0.663***
	[0.124]	[0.101]	[0.107]	[0.109]	[0.105]
Log(Revenue) (t-1)	0.276**	0.280***	0.211*	0.235**	0.212*
	[0.123]	[0.103]	[0.117]	[0.112]	[0.116]
Regulation authority & developing country	0.052***				
	[0.020]				
Regulation authority & developed country	0.059**				
	[0.024]				
Regulatory mandate & developing country		0.056**			
		[0.027]			
Regulatory mandate & developed country		0.068**			
		[0.034]			
Regulatory regime & developing country			0.027**		
			[0.013]		
Regulatory regime & developed country			0.026**		
			[0.013]		
Competition framework & developing country				0.038**	
				[0.016]	
Competition framework & developed country				0.039**	
				[0.016]	
ICT Regulatory Tracker (overall) & developing country					0.012**
					[0.005]
ICT Regulatory Tracker (overall) & developed country					0.012**
					[0.005]
Arellano-Bond test AR(1) first differences	-1.77*	-1.76*	-1.76*	-1.77*	-1.76*
Arellano-Bond test AR(2) first differences	0.95	0.96	0.97	0.94	0.96
Over-identification test (Hansen J-test)	134.30	134.90	137.46	136.35	136.21
Time-trend	YES	YES	YES	YES	YES
Observations	826	826	826	826	826

*Notes: *p<10%, **p<5%, ***p<1%. Robust standard errors in brackets. Policy variables in columns [I] to [V] treated as endogenous using the respective second lag as instruments.*

Additionally, in order to be more policy-relevant, further estimates were carried out relying on additional variables to dig deeper into each of these areas, to identify what ingredients in the regulatory environment matter the most (Table E.3). In column [I] in Table E.3 the variable of profit tax affecting the business sector was introduced, which exhibits a negative and significant coefficient. Thus, the larger the taxation pressure imposed on the operators, the lower the investment.

Table E.3: Overall sector: two-step GMM estimation results

Investment equation - specific policy and regulatory variables							
Dep. var. = Log(CAPEX)	**[I]**	**[II]**	**[III]**	**[IV]**	**[V]**	**[VI]**	**[VII]**
Log(CAPEX) (t-1)	0.541***	0.515***	0.634***	0.589***	0.581***	0.630***	0.615***
	[0.139]	[0.184]	[0.114]	[0.131]	[0.133]	[0.124]	[0.157]
Log(Revenue) (t-1)	0.351***	0.387**	0.258**	0.290**	0.294**	0.276**	0.275*
	[0.126]	[0.173]	[0.108]	[0.124]	[0.124]	[0.117]	[0.143]
Log(Profit tax)	-0.275*						
	[0.160]						
Log(Time to start a business)		-0.341**					
		[0.147]					
SMP			0.221**				
			[0.106]				
OECD				0.361*			
				[0.213]			
OECD (years)					0.009*		
					[0.005]		
WTO						0.283	
						[0.276]	
WTO (years)							0.035*
							[0.019]
Arellano-Bond test AR(1) first differences	-1.78*	-1.83*	-1.77*	-2.23**	-2.23**	-2.26**	-2.20**
Arellano-Bond test AR(2) first differences	0.95	0.94	0.94	1.02	1.02	1.02	1.02

Table E.3: Overall sector: two-step GMM estimation results (continued)

Investment equation - specific policy and regulatory variables							
Dep. var. = Log(CAPEX)	[I]	[II]	[III]	[IV]	[V]	[VI]	[VII]
Over-identification test (Hansen J-test)	129.83	140.00	136.57	124.87	126.85	133.20	133.05
Time-trend	YES	YES	YES	YES	YES	YES	YES
Observations	734	801	826	826	826	826	826

*Notes: *p<10%, **p<5%, ***p<1%. Robust standard errors in brackets. Policy variables in columns [I] to [IV] treated as endogenous using the respective second lag as instruments*.

In turn, in column [II] the regressor of time required for doing business is introduced, as a measure of lower bureaucratic barriers to innovate. Even if this is not a sectoral variable -it refers to the overall economy-, it can be interpreted as a proxy for the government efficiency, or in other words, on the weight attributed to bureaucracy and other red-tape costs. As for the telecommunication sector, a larger value in this variable can be assimilated to slow permit-processes and administrative restrictions inhibiting network deployments. As expected, this variable turned out to be negative and statistically significant.

Next, in column [III], a variable is introduced that identifies the scope carried out in defining the concept of Significant Market Power (SMP). The coefficient associated was found to be positive and significant, which means that **the more monitored the competition levels are, the more dynamic the market turns, yielding larger investments** as a result.

Finally, the last four columns in Table E.3 –[IV] and [VII]- intend to measure the relevance for countries to become part of an international organization that promotes sound regulations and good practices to enhance a business-prone environment, such as the OECD and the WTO. In the case of OECD, belonging to this organization is linked to an increase in 36 per cent of investment, while when considering the years of membership, the result is also positive and significant. In the case of WTO, the dummy variable identifying the belonging to this group is not significant, but the years of membership it is. Then, **the longer the time a nation is a member of these organizations, the higher the network investment is**.

E.2 Estimation of the complete structural model for the mobile segment

The availability of data for the mobile segment facilitates the estimation of the complete model consisting of four equations. The estimation of the investment equation is similar as the carried out for the overall sector. Given that the dependent variable appears lagged at the right-hand side of the equation, the two-step GMM estimation approach is relied on as described above. The remaining three equations -coverage, price and adoption- do not exhibit the "dynamic panel bias" but will have to take into account the presence of endogenous regressors, those variables that are at the left-hand side of the other equations. Thus, for these estimates the Instrumental Variables – Limited Information Maximum Likelihood approach (IV-LIML) is relied on, which is known to behave considerably better than the conventional IV-2SLS estimate under deviations from the standard assumptions.

E.2.1 Estimation of the investment model

The investment equation links CAPEX with its own lagged value and to past sectoral revenues.[40] With that baseline framework defined for the investment equation, specific variables related to the regulatory environment that may affect investment decisions are individually introduced. Results are reported in Table E.4.

In column [I], the dummy variable is introduced, indicating those cases in which a national broadband plan has been developed. As expected, the enactment of this plan, that can be interpreted a proxy for displaying political leadership in terms of a digital agenda, is accompanied by an increase in investment levels. In column [II], a proxy for convergent licences is introduced as a regressor, built from the nature and scope of the licensing framework. Results indicate that the wider the scope of the licences, the larger the investments. This may be explained due to the fact that convergent licensing constitutes a flexible approach, more adapted to technological advances, thereby contributing to maximize the financial returns of investments. Next, in column [III] a dummy variable is added identifying when voluntary sharing of active infrastructures is permitted. As expected, this variable exhibits a positive and significant coefficient, which allows to maximize the opportunities for operators to make their investments profitable. In addition, the profit tax introduced in column [IV], which as in the case of the overall sector, shows a negative and significant coefficient. That is to say, the larger the profit taxes imposed on the telecommunications operators, the lower the investment levels.

Next, several variables linked to competition are introduced. In column [V] the requirement of mobile portability is introduced, which was found to make the market more dynamic, as it seems to be promoting investment. Column [VI] adds a dummy variable that identifies those cases in which no restrictions are placed on foreign spectrum-based operators. As expected, when the market is open to foreign competition, investment is stimulated. Next, as in the case of the overall sector, the SMP and competition authority variables are introduced (in columns [VII] and [VIII], respectively) showing the expected results.

Further, in order to assess the joint introduction of regulatory variables, a 'regulatory scale' was built using as sub indicators those policy variables that matter the most: broadband plan, convergent licences, spectrum sharing allowed, mobile portability, no restrictions for foreign mobile operators, and competition authority. The scale takes values from zero to six depending on the number of the former attributes each country fulfils. Results exposed in column [IX] suggest that the more policies are enacted, the larger the impact on investment.

Finally, in column [X] an estimation was carried out adding the HHI index (variable which is included in levels and in squares) to take into account the inverted-U link described in Aghion *et al.* (2005). The results show both variables to be statistically significant, with the level equation exhibiting a positive coefficient while that of the squared-regressor a negative sign. This provides support to the theory of the inverted-U, linking competition and investment.

E.2.2 Estimation of the coverage model

The second equation has as dependent variable the level of 4G coverage, as a function of mobile *CAPEX* (in lags, given that investment takes some time to materialize into effective coverage gains). We decided to approximate past investment by mobile *CAPEX* in period *t-2*,

[40] External instruments added: lagged variables referred to coverage indicators, SMP and mobile prices.

Table E.4: Mobile sector: two-step GMM estimation results

Investment equation - specific policy and regulatory variables										
Dep. var. = Log(Mobile CAPEX)	[I]	[II]	[III]	[IV]	[V]	[VI]	[VII]	[VIII]	[IX]	[X]
Log(Mobile CAPEX) (t-1)	0.829***	0.816***	0.789***	0.662***	0.807***	0.842***	0.803***	0.804***	0.791***	0.808***
	[0.078]	[0.080]	[0.087]	[0.065]	[0.078]	[0.091]	[0.086]	[0.087]	[0.094]	[0.066]
Log(Mobile Revenue) (t-1)	0.139*	0.149**	0.174**	0.307***	0.141*	0.130	0.153*	0.149*	0.146*	0.153**
	[0.073]	[0.075]	[0.080]	[0.063]	[0.074]	[0.086]	[0.081]	[0.084]	[0.087]	[0.062]
Broadband plan	0.151***									
	[0.049]									
Convergent licences		0.050**								
		[0.025]								
Spectrum sharing allowed			0.183*							
			[0.101]							
Log(Profit tax)				-0.048*						
				[0.029]						
Mobile portability					0.108**					
					[0.051]					
No restriction for foreign mobile operators						0.144*				
						[0.087]				
SMP							0.025*			
							[0.015]			

Table E.4: Mobile sector: two-step GMM estimation results (continued)

Investment equation - specific policy and regulatory variables										
Dep. var. = Log(Mobile CAPEX)	[I]	[II]	[III]	[IV]	[V]	[VI]	[VII]	[VIII]	[IX]	[X]
Competition authority								0.096*		
								[0.050]		
Regulatory scale									0.051**	
									[0.020]	
Log(HHI mobile)										8.938**
										[4.419]
Log(HHI mobile) - squared										-0.537**
										[0.268]
Arellano-Bond test AR(1) first differences	-4.53***	-4.25***	-4.34***	-5.29***	-4.36***	-5.74***	-4.41***	-4.43***	-5.40***	-5.60***
Arellano-Bond test AR(2) first differences	-0.92	-0.88	-0.99	-0.38	-0.94	-0.69	-0.98	-0.98	-0.38	-1.07
Over-identification test (Hansen J-test)	105.12	105.02	107.94	102.02	110.21	100.28	109.52	99.22	109.28	122.89
Time-trend	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Observations	641	641	641	448	641	634	641	641	634	754

*Notes: *p<10%, **p<5%, ***p<1%. Robust standard errors in brackets. Policy variables in columns [I] to [VII] treated as endogenous, using the respective second lag as instruments. In estimate reported in column [IV] we add as further instruments the lags of mobile and revenue taxation, while in the estimate reported in column [VI] we add the third lag of the policy variable as instrument. Policy variable in column [VIII] instrumented through its first lag. Policy variable in column [IX] instrumented through its eight lag.*

as it provided to be more relevant than CAPEX in period *t-1* to explain coverage in period *t*. 4G Coverage is expected to depend also on past coverage levels (defined for cellular technology rather than 4G specific, to avoid entering the lagged dependent variable as regressor), and on the percentage of urban population. The estimated regression also includes country fixed effects, which allow to control for national-level time-invariant unobservable factors. In addition, year fixed effects were included to account for economic cycle variations.

The CAPEX in *t-2* regressor was treated as endogenous, as determined in the previous equation. As instruments, those determinants of CAPEX were introduced as defined in the investment equation.[41] Instruments were verified to be exogenous, according to the result of the Hansen-J test. On the other hand, the contrast of weak identification and under identification point at the explanatory power of the selected instruments. Table E.5 summarizes the results.

Table E.5: Mobile sector: IV-LIML estimation results

Coverage equation	
Dependent variable = Log(4G Coverage)	
Log(Mobile CAPEX) (t-2)	0.936*** [0.312]
Log(Cellular coverage) (t-1)	2.140*** [0.564]
Log(Cellular coverage) (t-2)	1.918*** [0.458]
Log(Cellular coverage) (t-3)	1.223*** [0.260]
Log(Urban population)	4.957*** [1.613]
Under identification test	25.869***
Weak identification test	33.305(†)
Over-identification test (Hansen J-test)	0.061
Country Fixed Effects	YES
Year Fixed Effects	YES
Observations	772

*Notes: *p<10%, **p<5%, ***p<1%. Robust standard errors in brackets. (†) Stock-Yogo weak ID test critical values: 10% maximal LIML size: 8.68*.

Results are in line as those expected. Past mobile investment is significant to explain current 4G coverage levels, as are the past coverage levels for previous technologies. In addition, more urban countries exhibit larger coverage levels, which is reasonable as investment is more profitable in such contexts.

41 To instrument log (CAPEX Mobile) in *t-2* uses as instruments log (CAPEX mobile) in *t-3* and log (Revenue mobile) in *t-3*.

E.2.3 Estimation of the price model

The third equation links mobile broadband prices with taxation of mobile services, 4G coverage and competitive pressures. To control for competition levels, the SMP variable as defined above was relied on. The estimated regression also includes country fixed effects, which allow to control for national-level time-invariant unobservable factors. In addition, year fixed effects were included to account for economic cycle variations. Coverage is assumed to be endogenous, and the determinants are used as instruments as defined in the previous equation.[42] Instruments were verified to be exogenous, according to the result of the Hansen-J test. On the other hand, the contrast of weak identification and under identification provide the desired results in terms of their explanatory power. Table E.6 summarizes the results.

Table E.6: Mobile sector: IV-LIML estimation results

Price equation	
Dependent variable = Log (Mobile Price)	
Log (4G Coverage)	-0.583*** [0.133]
Mobile tax	0.017** [0.008]
SMP	-0.191*** [0.061]
Under identification test	34.940***
Weak identification test	15.961(†)
Over-identification test (Hansen J-test)	5.670
Country Fixed Effects	YES
Year Fixed Effects	YES
Observations	695

*Notes: *p<10%, **p<5%, ***p<1%. Robust standard errors in brackets. (†) Stock-Yogo weak ID test critical values: 10% maximal LIML size: 4.84.*

As expected, the more expanded the coverage is, the lower the service prices are. In turn, the larger the taxation imposed on mobile services, the more expensive the end-user prices are. Finally, the more monitored the competition in the market is (as denoted by the SMP indicator), the lower the prices.

E.2.4 Estimation of the ICT adoption equation

Finally, the adoption equation, links demand (measured as mobile broadband unique subscriber penetration) as a function of prices, coverage, income (proxied by the GDP per capita, lagged to avoid causality concerns) and the age composition of the population. The estimated regression

42 Instruments for log(4G Coverage) are log(Urban), the second lag of log(Mobile CAPEX), and the first to third lags of log(Cellular coverage).

also includes country fixed effects, which allow to control for national-level time-invariant unobservable factors. In addition, year fixed effects are included to account for economic cycle variations. Both price and coverage regressors are assumed to be endogenous, and the lagged valued of both variables as instruments.[43] Instruments were verified to be exogenous, according to the result of the Hansen-J test. On the other hand, the contrast of weak identification and under identification provide the desired results in terms of its explanatory power. Table E.7 summarizes the results.

Table E.7: Mobile sector: IV-LIML estimation results

Demand equation	
Dependent variable = Log(MBB penetration)	
Log(Mobile Price)	-0.202*** [0.059]
Log(4G Coverage)	0.081* [0.048]
Log(GDP per capita) (t-1)	0.208** [0.094]
Share population over 65 years	-0.067*** [0.019]
Under identification test	24.918***
Weak identification test	16.546(†)
Over-identification test (Hansen J-test)	0.421
Country Fixed Effects	YES
Year Fixed Effects	YES
Observations	695

*Notes: *p<10%, **p<5%, ***p<1%. Robust standard errors in brackets. (†) Stock-Yogo weak ID test critical values: 10% maximal LIML size: 5.44.*

The results suggest that, as expected, demand is negatively linked to prices. The higher the prices, the lower the adoption level. On the other hand, 4G Coverage exhibits a positive and significant coefficient, which suggest that the more expanded the networks are, the larger the adoption levels. Finally, income as measured by the lag of GDP per capita explains positively the adoption levels, and the older the composition of the population, the lower the demand.

[43] Instrument for Log(Mobile Price) is its own first lag. Instruments for Log(4G Coverage) are its first and second lags.

E.2.5 Macroeconomic outcomes

From equation [1], it seems straightforward to calculate the effect on investment decisions from a certain policy or institutional reform:

$$\frac{\partial \log(CAPEX_t)}{\partial X_t} = \delta$$

Turning next to equation [2], the impact that will yield in coverage improvement can be assessed by considering the CAPEX gains as a result of *X*:

$$\frac{\partial \log(COVERAGE_{t+i})}{\partial X_t} = \Phi\left[\frac{\partial \log(CAPEX_t)}{\partial X_t}\right] = \Phi\delta$$

Note that the increase in coverage happens in period *t+i*, as CAPEX improvements do not materialize immediately into coverage gains (recall that *i=2 is* defined in the model estimated in Table E.7). In turn, coverage increases as a result of all the above are expected to bring down prices:

$$\frac{\partial \log(PRICES_{t+i})}{\partial X_t} = \Psi\left[\frac{\partial \log(COVERAGE_{t+i})}{\partial X_t}\right] = \Psi\Phi\delta < 0$$

The prices will be reduced as long as , as shown in our results. Finally, coverage increases and prices reduced will yield an increase in demand:

$$\frac{\partial \log(DEMAND_{t+i})}{\partial X_t} = \eta\left[\frac{\partial \log(PRICES_{t+i})}{\partial X_t}\right] + \tau\left[\frac{\partial \log(COVERAGE_{t+i})}{\partial X_t}\right] = \Phi\delta(\eta\Psi + \tau) > 0$$

The variation in demand will be positive given that and . In this model *DEMAND* is measured as mobile broadband unique subscriber penetration (*MBB pen*). Substituting and rearranging:

$$\partial \log(MBB\ pen_{t+i}) = \Phi\delta(\eta\Psi + \tau)\partial X_t \qquad [5]$$

As a result, what started in period *t* with a certain policy or institutional reform *X* turned into an increase in adoption in period *t+i*. In turn, an increase of broadband adoption has been widely associated in the specialized literature with macroeconomic gains, in terms of GDP and GDP per capita. In order to assess the magnitude of this impact, Katz and Callorda (2018) estimated coefficients were relied on for the case of an improvement in mobile broadband unique subscriber adoption, as highlighted in Table E.8.

Table E.8: Mobile broadband impact on GDP per capita

Dependent variable = Log(GDP per capita)	
Log(MBB penetration)	0.150***
Capital	0.215***
Education	0.056***
Country Fixed Effects	YES
Year and quarter fixed effects	YES
R-squared	0.995
Observations	3858

Source: Katz and Callorda (2018)

*Notes: ***p<1%.*

As Table E.8 indicates, an increase of 1 per cent in mobile broadband unique subscriber penetration yields a 0.15 per cent increase in GDP per capita. We will use that coefficient in order to analyse the macroeconomic impact created after *X*:

$$\frac{\partial \log(GDP\ pc_{t+i})}{\partial \log\left(MBB\ pen_{t+i}\right)} = 0.15$$

Which can be expressed as:

$$\partial \log(GDP\ pc_{t+i}) = 0.15\ \partial \log(MBB\ pen_{t+i})$$

Substituting the previous equation with the results reported in [5]:

$$\partial \log(GDP\ pc_{t+i}) = 0.15 \mp \delta(\eta\psi + \tau)\partial X_t$$

Therefore, the GDP per capita growth rate will depend on the estimated parameters of the structural model. However, given the dynamics of our model, the positive impact of policy and institutional reforms will translate into further gains beyond a single period, as CAPEX in future years will continue to grow as a result of the improvements in its own past values. Thus, each time that investment increases, it will translate into future economic gains in terms of GDP, but in addition, it will result in further CAPEX improvements in the next periods, which in turn will yield further economic gains. The next section focuses on analysing specific policy simulations.

The impact of promoting a national broadband plan

Starting from period *t*, a hypothetical country decides to promote a national broadband plan. Column [I] table E.4 provides the reference parameters for the investment equation. In period *t*, investment increases 15.10 per cent, as a result of the policy decision to adopt a broadband plan. Recall that this is simply the measure of the average effect linked to the political decision to implement a broadband plan, not contemplating the contents and characteristics of the plan. The CAPEX increase will yield in period *t+2* an increase in coverage (+14.13%), which in turn will contribute to reduce prices (-8.24%), and will yield an overall growth of 2.81 per cent in mobile broadband penetration. Given the impact of mobile broadband on GDP, this adoption gain will translate into a GDP per capita increase of 0.42 per cent in period *t+2*. However, as depicted in Figure 4, CAPEX increase will also translate into future investment increases, which in turn will trigger further improvements in terms of coverage, prices, adoption and GDP per capita. That process will continue to happen for some years, until the effect languishes and finally tends to zero. Table E.9 summarizes the results.

Table E.9: Policy simulation effects: National broadband plan

Item	Period										
	t	t+1	t+2	t+3	t+4	t+5	t+6	t+7	t+8	t+9	t+10
Impact on CAPEX	15.10%	12.52%	10.38%	8.60%	7.13%	5.91%	4.90%	4.06%	3.37%	2.79%	2.31%
Impact on COVERAGE	0.00%	0.00%	14.13%	11.72%	9.71%	8.05%	6.68%	5.53%	4.59%	3.80%	3.15%
Impact on PRICES	0.00%	0.00%	-8.24%	-6.83%	-5.66%	-4.69%	-3.89%	-3.23%	-2.67%	-2.22%	-1.84%
Impact on MBB penetration	0.00%	0.00%	2.81%	2.33%	1.93%	1.60%	1.33%	1.10%	0.91%	0.76%	0.63%
Impact on GDP per capita	0.00%	0.00%	0.42%	0.35%	0.29%	0.24%	0.20%	0.16%	0.14%	0.11%	0.09%

Source: Telecom Advisory Services

Convergent licensing

As shown in Table E.4, a convergent licensing approach has the effect of spurring investment in the mobile sector. Starting in period *t* with restrictive licensing framework (a value of 0 in the convergent licence score that takes values from 0 to 2), if unique licences are adopted this will facilitate the possibility of operators to expand their activities and offer a wider range of services. According to the parameters of the model, the country will reach an increase in investment of 10 per cent at the time of the reforms, which will translate in *t+2* into 9.36 per cent coverage increase, price reduction of -4.45 per cent, penetration growth of 1.86 per cent, and GDP gains of 0.28 per cent. As in the previous case, the effect will propagate through the following periods till vanish. Table E.10 summarizes the results.

Table E.10: Policy simulation effects: implementing convergent licences

Item	Period										
	t	t+1	t+2	t+3	t+4	t+5	t+6	t+7	t+8	t+9	t+10
Impact on Capex	10.00%	8.16%	6.66%	5.43%	4.43%	3.62%	2.95%	2.41%	1.97%	1.60%	1.31%
Impact on Coverage	0.00%	0.00%	9.36%	7.64%	6.23%	5.09%	4.15%	3.39%	2.76%	2.25%	1.84%
Impact on Prices	0.00%	0.00%	-5.46%	-4.45%	-3.63%	-2.96%	-2.42%	-1.97%	-1.61%	-1.31%	-1.07%
Impact on MBB penetration	0.00%	0.00%	1.86%	1.52%	1.24%	1.01%	0.82%	0.67%	0.55%	0.45%	0.37%
Impact on GDP per capita	0.00%	0.00%	0.28%	0.23%	0.19%	0.15%	0.12%	0.10%	0.08%	0.07%	0.05%

Source: Telecom Advisory Services

Spectrum sharing allowed

As shown in Table E.4, the possibility of allowing spectrum sharing agreements has the effect of spurring investment in the mobile sector. Starting in period *t*, if this regulatory reform is adopted, the country will reach an increase in investment of 18.3 per cent at the time of the reforms, which will translate in *t+2* into 17.13 per cent coverage increase, price reduction of -9.99 per cent, penetration growth of 3.40 per cent, and GDP gains of 0.51 per cent. As in the previous cases, the effect will propagate through the following periods till vanish. Table E.11 summarizes the results.

Table E.11: Policy simulation effects: spectrum sharing allowed

Item	Period										
	t	t+1	t+2	t+3	t+4	t+5	t+6	t+7	t+8	t+9	t+10
Impact on Capex	18.30%	14.44%	11.39%	8.99%	7.09%	5.60%	4.41%	3.48%	2.75%	2.17%	1.71%
Impact on Coverage	0.00%	0.00%	17.13%	13.51%	10.66%	8.41%	6.64%	5.24%	4.13%	3.26%	2.57%
Impact on Prices	0.00%	0.00%	-9.99%	-7.88%	-6.22%	-4.90%	-3.87%	-3.05%	-2.41%	-1.90%	-1.50%
Impact on MBB penetration	0.00%	0.00%	3.40%	2.69%	2.12%	1.67%	1.32%	1.04%	0.82%	0.65%	0.51%
Impact on GDP per capita	0.00%	0.00%	0.51%	0.40%	0.32%	0.25%	0.20%	0.16%	0.12%	0.10%	0.08%

Source: Telecom Advisory Services

Mobile portability

As shown in Table E.4, the possibility of adopting mobile number portability has the effect of making more dynamic the mobile sector. Starting in period *t*, if this regulatory reform is adopted, the country will reach an increase in investment of 10.8 per cent at the time of the reforms, which will translate in *t+2* into 10.11 per cent coverage increase, price reduction of -5.89 per cent, penetration growth of 2.01 per cent, and GDP gains of 0.3 per cent. As in the previous cases, the effect will propagate through the following periods till vanish. Table E.12 summarizes the results.

Table E.12: Policy simulation effects: mobile portability

Item	Period										
	t	t+1	t+2	t+3	t+4	t+5	t+6	t+7	t+8	t+9	t+10
Impact on Capex	10.80%	8.72%	7.03%	5.68%	4.58%	3.70%	2.98%	2.41%	1.94%	1.57%	1.27%
Impact on Coverage	0.00%	0.00%	10.11%	8.16%	6.58%	5.31%	4.29%	3.46%	2.79%	2.25%	1.82%
Impact on Prices	0.00%	0.00%	-5.89%	-4.76%	-3.84%	-3.10%	-2.50%	-2.02%	-1.63%	-1.31%	-1.06%
Impact on MBB penetration	0.00%	0.00%	2.01%	1.62%	1.31%	1.06%	0.85%	0.69%	0.55%	0.45%	0.36%
Impact on GDP per capita	0.00%	0.00%	0.30%	0.24%	0.20%	0.16%	0.13%	0.10%	0.08%	0.07%	0.05%

Source: Telecom Advisory Services

Openness to foreign operators

Assume a country with restrictions to the participation of foreign operators. If the authorities decide to pursue a reform intending to eliminate those restrictions, foreign operators will be able to invest in the local market, generating a dynamic effect. According to the parameters estimated in column [VI] of Table E.4, investment in period *t* will increase in 14.40 per cent, and this will trigger improvements in *t+2* in terms of coverage (+13.48%), prices (-7.86%), adoption (+2.68%) and GDP per capita (+0.40%). Table E.13 summarizes the results.

Table E.13: Policy simulation effects: openness to foreign operators

Item	Period										
	t	t+1	t+2	t+3	t+4	t+5	t+6	t+7	t+8	t+9	t+10
Impact on CAPEX	14.40%	12.12%	10.21%	8.60%	7.24%	6.09%	5.13%	4.32%	3.64%	3.06%	2.58%
Impact on COVERAGE	0.00%	0.00%	13.48%	11.35%	9.56%	8.05%	6.77%	5.70%	4.80%	4.04%	3.41%
Impact on PRICES	0.00%	0.00%	-7.86%	-6.62%	-5.57%	-4.69%	-3.95%	-3.33%	-2.80%	-2.36%	-1.99%
Impact on MBB penetration	0.00%	0.00%	2.68%	2.26%	1.90%	1.60%	1.35%	1.13%	0.95%	0.80%	0.68%
Impact on GDP per capita	0.00%	0.00%	0.40%	0.34%	0.28%	0.24%	0.20%	0.17%	0.14%	0.12%	0.10%

National competition authority

As shown in Table E.4, the creation of a national competition authority contributes to improve market monitoring to avoid uncompetitive practices, yielding in better outcomes as a result. Starting in period *t*, the country will reach an increase in investment of 9.6 per cent at the time of the reform, which will translate in *t+2* into 8.99 per cent coverage increase, price reduction of -5.24 per cent, penetration growth of 1.79 per cent, and GDP gains of 0.27 per cent. As in the previous cases, the effect will propagate through the following periods till vanish. Table E.14 summarizes the results.

Table E.14: Policy simulation effects: National competition authority

Item	Period										
	t	t+1	t+2	t+3	t+4	t+5	t+6	t+7	t+8	t+9	t+10
Impact on Capex	9.60%	7.72%	6.21%	4.99%	4.01%	3.23%	2.59%	2.08%	1.68%	1.35%	1.08%
Impact on Coverage	0.00%	0.00%	8.99%	7.22%	5.81%	4.67%	3.75%	3.02%	2.43%	1.95%	1.57%
Impact on Prices	0.00%	0.00%	-5.24%	-4.21%	-3.39%	-2.72%	-2.19%	-1.76%	-1.41%	-1.14%	-0.91%
Impact on MBB penetration	0.00%	0.00%	1.79%	1.44%	1.15%	0.93%	0.75%	0.60%	0.48%	0.39%	0.31%
Impact on GDP per capita	0.00%	0.00%	0.27%	0.22%	0.17%	0.14%	0.11%	0.09%	0.07%	0.06%	0.05%

Source: Telecom Advisory Services

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