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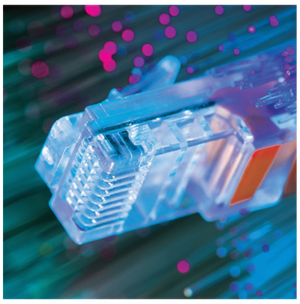
Economic impact of broadband in LDCs, LLDCs and SIDS

An empirical study












UN-OHRLLS

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Acknowledgements

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Foreword

The United Nations Office of the High Representative for the Least Developed Countries, Landlocked Developing Countries and Small Island Developing States (UN-OHRLLS) and the Telecommunication Development Bureau (BDT) of the International Telecommunication Union (ITU) are pleased to share with you a report on the *'Economic impact of broadband in the least developed countries (LDCs), landlocked developing countries (LLDCs) and small island developing states (SIDS)'*.

These three groups of countries constitute 91 of the world's most vulnerable nations. Some of them lag significantly behind in terms of achieving the Sustainable Development Goals (SDGs). As part of the ongoing global efforts to help countries implement the 2030 Agenda for Sustainable Development, it is necessary to pay particular attention to these groups of countries.

With the onset of the digital economy and the technological revolution, broadband connectivity, or, more broadly, access to fast Internet, is a necessity if countries are to participate effectively in the global economy. Indeed, broadband is an enabling technology, as it supports existing and new applications in many different sectors, including education, government, financial services, health, disaster management and e-commerce. Yet broadband Internet access in the majority of the LDCs, LLDCs and SIDS remains below the global average.

Notwithstanding anecdotal evidence of the positive impact of broadband on economic, human and social outcomes, there are very few studies that quantify these positive contributions at the macro level. Moreover, most of the existing studies are not current, and hence do not take account of the improvement in access to broadband and its application in a growing number of activities and industries. To fill this gap, ITU and UN-OHRLLS joined forces to prepare this study and assess the economic impact of broadband in LDCs, LLDCs and SIDS.

The findings of the study confirm that both fixed and mobile broadband have a positive economic impact in the most vulnerable countries. The impact of broadband appears to be stronger with increased penetration. For both fixed and mobile technologies, the analysis finds that gross domestic product (GDP) per capita is related to broadband penetration, indicating an increase in economic impact as broadband penetration increases. Since the relative impact of both fixed and mobile broadband is greater in vulnerable countries than in other developing and developed countries, LDCs, LLDCs and SIDS would do well to implement policies that focus on further investment in improving broadband access, connectivity and uptake.

It is therefore our hope that this study will serve as an important advocacy tool in support of investment aimed at broadband access, connectivity and use in LDCs, LLDCs and SIDS. This investment could yield even higher economic returns than in other countries, and propel these vulnerable nations towards achievement of the SDGs.

Fekitamoeloa Katoa ʻUtoikamanu
Under-Secretary-General, and High Representative for the Least Developed Countries, Landlocked Developing Countries and Small Island Developing States

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Executive summary

This empirical study examines the economic impact of fixed and mobile broadband in the least developed countries (LDCs), landlocked developing countries (LLDCs) and small island developing states (SIDS). These 91 most vulnerable countries have to date been largely neglected in studies of this kind, yet broadband technology offers potential for a step change in their economic and social development. A growing body of evidence indicates that broadband Internet, and information and communication technologies (ICT) in general, promote economic development. Given its potential applications in diverse sectors of the economy, investment in this technology is particularly important for vulnerable countries. Failure to ensure high levels of broadband access and use may have significant implications for these countries, with the risk of seeing them fall further behind.

As an enabling technology, broadband creates value and reduces costs by supporting applications in many different sectors such as agriculture, education, financial services, government, health and disaster management. Case studies already show a quantifiable economic impact – for example, fixed and mobile broadband have facilitated e-commerce in Kazakhstan, which continues to expand, generating additional revenue and employment. In some LDCs, the indirect impact of these technologies is difficult to quantify, but economic and social effects are emerging, particularly in relation to improvements in the quality of education. For example, in Ethiopia and Zambia, e-education initiatives supported by broadband technologies are expanding opportunities for learning at the vitally important primary school stage and for tertiary study. Ultimately, broadband is expected to have a positive impact on GDP per capita, since student achievement and skills are strong predictors for their future socio-economic status.

Using a cross-sectional time-series analysis, this study explores the economic impact of broadband in LDCs, LLDCs and SIDS over the period 2000 to 2017. Its findings confirm that both fixed and mobile broadband have a positive economic impact in these countries. Mobile broadband appears to exert a slightly stronger impact than fixed broadband, generating a 2.5 to 2.8 per cent increase in GDP per capita per 10 per cent increase in penetration, compared to a 2.0 per cent to 2.3 per cent increase for fixed broadband. However, as the difference is not statistically significant it is not possible to conclude that mobile delivers a superior outcome to fixed broadband.

For both fixed and mobile technologies, the analysis finds that GDP per capita is related to broadband penetration, indicating an increase in economic impact as broadband penetration increases. Threshold effects were evident for mobile broadband at a level of at least 30 mobile broadband subscriptions per 100 inhabitants. In the case of fixed broadband, low levels of penetration in almost all of the sample countries mean that threshold effects are more difficult to identify.

From a comparison of these results with other empirical studies (Figure 0.1), it appears that the economic impact of both fixed and mobile broadband is greater in low-income countries than in other, higher-income countries. This indicates that a policy of increased or further investment in improving broadband access, connectivity and uptake in LDCs, LLDCs and SIDS could yield higher economic returns than in other countries.

Figure 0.1: Economic impact of broadband in LLDCs, LDCs and SIDS versus impact in developed and developing countries

10 per cent increase in fixed-broadband penetration
→ increase in GDP/capita
- **2.0 to 2.3 per cent**

10 per cent increase in mobile-broadband penetration
→ increase in GDP/capita
- **2.5 to 2.8 per cent**

ITU (2019)
47 (fixed broadband) and 62 (mobile broadband) LDCs, LLDCs and SIDS
2000-2017 annual data

10 per cent increase in fixed-broadband penetration
→ increase in GDP
- **0.8 per cent**

10 per cent increase in mobile-broadband penetration
→ increase in GDP
- **1.5 per cent**

ITU (2018)
Full sample of 139 developed and developing countries
2010-2017 quarterly data

One-time effect in the year fixed-broadband was introduced → increase in growth of GDP/capita
- **3.06 per cent**

Thereafter 10 per cent increase in fixed-broadband
→ annual increase in growth of GDP/capita
- **0.01 percentage points**

Candelaria (2015)
35 developed and developing countries
1981-2013 annual data

10 percentage point increase in fixed-broadband penetration
→ increase in growth of GDP/capita
- **1.21 percentage points** (high-income countries)
- **1.38 percentage points** (low- and middle-income countries)

World Bank (2009)
120 countries
1980-2006 annual data

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1 Introduction

Although a number of studies have attempted to measure the economic impact of broadband services, few recent analyses have focused solely on developing countries. This is largely explained by data issues, including the lack of sufficiently reliable or long time series to support meaningful statistical analysis. In order to assess the economic effect of the uptake of broadband services, this study encompasses a cross-sectional time-series analysis with a focus on least developed countries (LDCs), landlocked developing countries (LLDCs) and small island developing states (SIDS), for the period 2000 to 2017.

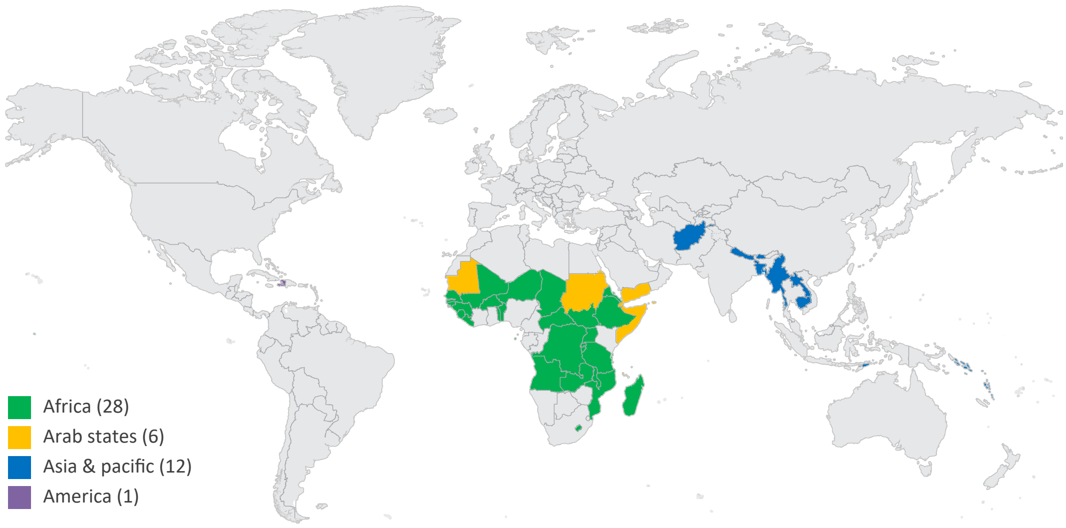
The empirical analysis has been supplemented by 'real-life' case-study evidence of the economic and social impact of broadband applications in different sectors.

1.1 Study sample

The LDCs comprise 47 low-income countries that are suffering from long-term impediments to sustainable development. These countries tend to display low levels of human development and are vulnerable to economic and environmental shocks as they typically rely on the export of a few primary commodities as a major source of earnings. The combined population of the LDCs represents about 12 per cent of the world population; however, they account for less than 2 per cent of world GDP.[1]

While the majority of the LDCs are in Africa, there are also several in the Asia and Pacific region and a handful in the Arab States and the Americas (Figure 1.1). The LDCs also include a number of countries that are also classified as LLDCs or SIDS (Table 1.1).

Figure 1.1: Map of LDCs according to the ITU regional classification, 2018



Source: ITU and UN-OHRLLS

[1] UN-OHRLLS, *About LDCs*, accessed July 2018, http://unohrlls.org/about-ldcs/.

Table 1.1: List of LDCs by ITU region

Africa	Arab States	Asia and Pacific	Americas
LDCs that are not also LLDCs or SIDS			
Angola	Djibouti	Bangladesh	
Benin	Mauritania	Cambodia	
Democratic Republic of the Congo	Somalia	Myanmar	
Eritrea	Sudan		
Gambia	Yemen		
Guinea			
Liberia			
Madagascar			
Mozambique			
Senegal			
Sierra Leone			
Tanzania			
Togo			
LDCs that are also LLDCs			
Burkina Faso		Afghanistan	
Burundi		Bhutan	
Central African Republic		Lao PDR	
Chad		Nepal	
Ethiopia			
Lesotho			
Malawi			
Mali			
Niger			
Rwanda			
South Sudan			
Uganda			
Zambia			
LDCs that are also SIDS			
Guinea-Bissau	Comoros	Kiribati	Haiti
São Tomé and Príncipe		Solomon Islands	
		Timor-Leste	
		Tuvalu	
		Vanuatu	

Source: ITU, UN-OHRLLS

Whilst the developmental challenges facing the LDCs are often similar, there are major differences between the countries in terms of population, geography and economic development. In particular, LLDCs do not have direct access to the sea, making international connectivity more expensive due to reliance on land links via other countries. SIDS often comprise many islands which may be sparsely populated, and tend to have a narrow resource base, depriving them of economies of scale. They face high costs for energy, infrastructure, transportation and communications.

Both LLDCs and SIDS include a number of countries that are not classified as LDCs. These are listed in Table 1.2.

Table 1.2: LLDCs and SIDS that are not also LDCs

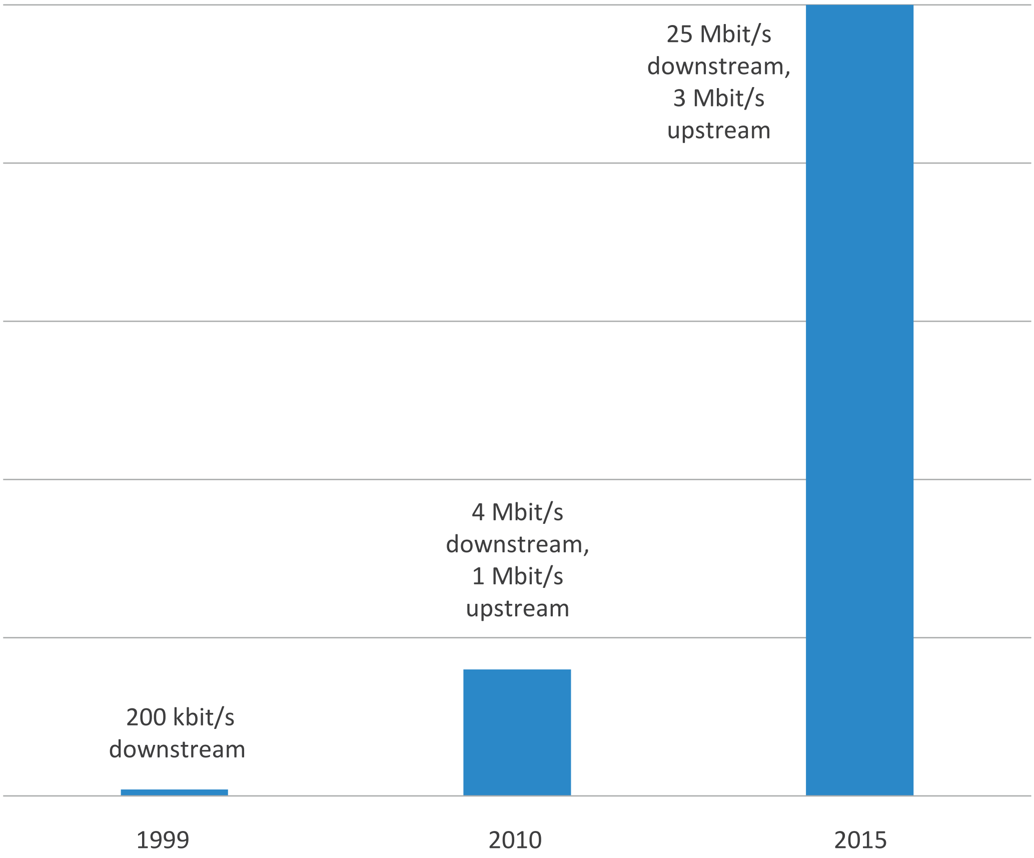
LLDCs	SIDS – UN members
Armenia	Antigua and Barbuda
Azerbaijan	Bahamas
Bolivia	Bahrain
Botswana	Barbados
Eswatini	Belize
Kazakhstan	Cabo Verde
Kyrgyzstan	Cuba
Mongolia	Dominica
Paraguay	Dominican Republic
Moldova	Fiji
North Macedonia	Grenada
Tajikistan	Guyana
Turkmenistan	Jamaica
Uzbekistan	Maldives
Zimbabwe	Marshall Islands
	Micronesia
	Mauritius
	Nauru
	Palau
	Papua New Guinea
	Samoa
	Singapore
	St. Kitts and Nevis
	St. Lucia
	St. Vincent and the Grenadines
	Seychelles
	Suriname
	Tonga
	Trinidad and Tobago

1.2 Definition of broadband

The traditional ITU definition of broadband is a minimum download speed of 256 kbit/s, provided over fixed or mobile connections. The ITU definition is also used by other organizations, such as OECD. However, other definitions may be used in some countries and organizations. Furthermore, these definitions may change over time to reflect the requirements of typical broadband user applications.

By way of example, the definition of broadband used by the FCC in 2015 encompassed a threefold increase in upstream speed and a sixfold increase in downstream speed in relation to the definition used only five years previously (Figure 1.2). As the present study uses ITU data, the definition of broadband matches that of ITU.[2]

Figure 1.2: Changing definition of broadband as used by the FCC in the United States



Source: FCC

1.3 Report structure

Following this introduction, the report is structured as follows:

- Key issues (Section 2)
- Approach (Section 3)
- Main findings (Section 4)
- Concluding remarks (Section 5).

The annexes provide:

- A full list of LDCs, LLDCs and SIDS
- Technical details relating to the modelling
- Bibliography.

[2] ITU also collects data on the number of fixed-broadband subscriptions broken down by speed of connection (256 kbit/s to 2 Mbit/s, 2 Mbit/s to 10 Mbit/s, and over 10 Mbit/s).

2 Key issues

2.1 Background

A seminal work by Bresnahan and Trajtenberg (1995) suggests that, throughout history, we observe a small number of 'technological prime movers' in the form of general purpose technologies (GPTs). There are clear instances of disruptive technological innovations that have had a revolutionary impact on societies and economies. Typical characteristics of such technologies include:

- technological dynamism
- potential for diffusion and pervasive use across many sectors
- enabling features that offer opportunities rather than complete solutions
- inducing and fostering general productivity gains
- 'innovational complementarities' – that is, innovation in the GPT leads to increased productivity of research and development in downstream (application) sectors.[3]

Arguably, broadband Internet exhibits the above characteristics and, as such, would qualify as the GPT of our age, as did the printing press, steam engines, electricity and motor vehicles in past eras. Broadband is an enabling technology, supporting existing and new applications in many different sectors such as education, government, financial services, health and disaster management. For individuals, the technology offers opportunities to improve personal circumstances, including better access to education, healthcare, government services and the labour market. For government, broadband supports e-government applications which introduce efficiencies and/or cost savings for both internal and customer-facing processes. In many cases, such processes were previously reliant on paper but are being moved online as broadband availability, uptake and usage increases. For businesses, the technology offers potential to improve productivity, expand market reach, increase revenues, decrease costs and increase employment. Moreover, there is growing evidence that broadband, and indeed ICT in general, improves market coordination and reduces information asymmetries and transaction costs, thereby promoting economic development.[4]

In addition to the indirect social and business effects highlighted above, investment in deploying broadband technologies leads to an expansion of the ICT sector. At the national level, this sectoral expansion returns many direct economic effects, including increased employment, changes in the balance of payments (via export/import flows) and growth in value added and higher government revenue (via taxation).[5]

Particularly through improving the quality of education, broadband is expected to have a positive impact on GDP per capita, since student achievement and skills are strong predictors for their future socio-economic status. While the impact of Internet access on secondary school students has been controversial,[6] due to counteracting factors subject to type of use, recent research suggests a positive association between broadband penetration in primary schools and student achievement. A recent study analysing the impact of ultrafast broadband access in primary schools in New Zealand indicates a small, but statistically significant, improvement in student achievement.[7] In particular, schools with higher proportions of students from poorer socio-economic backgrounds were found to benefit more from broadband. A similar study conducted in Irish primary schools associated the use of Internet

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[3] Timothy F. Bresnahan and Manuel Trajtenberg, "General purpose technologies 'Engines of growth'?", *Journal of Econometrics* 65, no. 1 (January 1995): 83–108.

[4] Hernan Galperin and M. Fernanda Viecens, "Connected for development? Theory and evidence about the impact of Internet technologies on poverty alleviation", *Development Policy Review*, 2017: 1-22. See Section 3.2.

[5] Empirical studies seeking to quantify these effects almost exclusively investigate the United States or OECD countries.

[6] Jacob L. Vigdor, Helen F. Ladd and Erika Martinez, "Scaling the digital divide: Home computer technology and student achievement", *Economic Inquiry*, 2014: 1103-1119.

[7] Arthur Grimes and Wilbur Townsend, "Effects of (ultra-fast) fibre broadband on student achievement", *Information Economics and Policy*, 44(C): 8-15.

in the class with higher test scores in mathematics and reading.[8] In general, access to broadband expands the resources available to teaching and facilitates student engagement.

Another potential pathway through which broadband can have an impact on economic welfare is by facilitating lifelong learning. A survey conducted by Pew Research in the United States concluded that adults with high-speed Internet access at home are 20 to 28 per cent more likely to engage in personal and professional learning activities than those without broadband access.[9]

Broadband technologies also are improving the quality of education in LDCs and promoting educational and social inclusiveness as access to the technologies expands to rural and remote regions. By way of example, the geographic and demographic features of Ethiopia present challenges in terms of educational standards for people living outside main centres. E-education and e-government initiatives are currently addressing these issues, although it is still too early to quantify the impact.

Ethiopia – E-government and e-education

WoredaNet links the central government to more than 611 "woredas"[1] and allows communication with some of the most remote corners of Ethiopia.[2] Each woreda site has a 42" flat-screen plasma television, voice-sensitive microphones and camera for videoconferencing, and at least two and up to five computers (Figure 2.1).[3] Broadband connectivity is provided terrestrially for nearly half of the sites, with the remainder communicating via VSAT (satellite) Internet. Terrestrial connectivity supports a 1 Mbit/s upstream data rate, while VSAT supports 512 kbit/s in order to carry outgoing video, voice and applications.

Figure 2.1: WoredaNet equipment, comprising, from top to bottom: a video camera, a plasma TV screen, a decoder and an amplifier/equalizer

Through WoredaNet, local officials can participate in videoconferencing, have access to court services and receive training and instructions. The key to successful implementation

1 "Woreda" is the word for an administrative division in Ethiopia managed by a local government.

2 1 World Connected, *Woredanet*, accessed November 2018. Available at http://1worldconnected.org/case-study/woredanet/

3 Civic Media Project, Mobilizing from above: Government use of ICTs for state and nation building in Ethiopia, accessed November 2018. Available at http://civicmediaproject.org/works/civic-media-project/woredanet-and-schoolnet-ethiopia

8 Marie Hyland, Richard Layte, Seán Lyons, Selina McCoy and Mary Silles, "Are classroom Internet use and academic performance higher after government broadband subsidies to primary schools?", *The Economic and Social Review*, 2015: 399-428.

9 John B. Horrigan, "Adults with tech-access tools are more likely to be lifelong learners and rely on the Internet to pursue knowledge", *Pew Research Centre*, 2015. Retrieved from http://www.pewinternet.org/2016/03/22/adults-with-tech-access-tools-are-more-likely-to-be-lifelong-learners-and-rely-on-the-internet-to-pursue-knowledge/

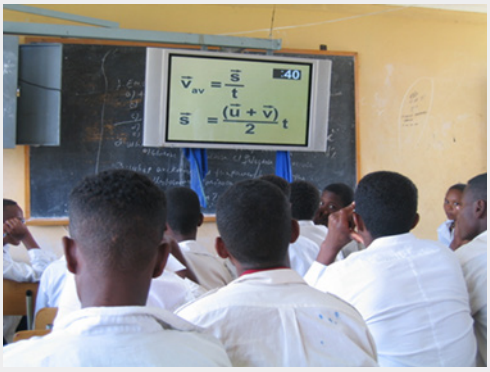
was overcoming the challenge of lack of telecommunication infrastructure in the country, which entailed:

- installing and commissioning broadband and VSAT equipment, and deploying multimedia infrastructure
- supplying and installing active networking and videoconferencing devices in 611+ woredas and performing end-to-end connectivity and functionality tests for all the technologies included in the project; as well as providing the woreda centres with the necessary furniture
- installing diesel generators in non-electrified areas
- selecting and providing mentorship and operational training for the final possessors of the system in the 611+ woreda sites
- preparing rooms to house the equipment and providing services in 600+ woredas.[1]

By October 2018, there were 976 woredas and over 5 000 government institutions connected.[2]

SchoolNet's objective is to enable students living in rural areas to have access to the same quality of education as those in the major towns and cities.[3] No fewer than16 686 plasma TV screens have been deployed to 775 schools in the country in order to receive broadcast lessons, on subjects ranging from mathematics to civic education (Figure 2.2). Connectivity is provided by optical fibre and VSAT. The aim was for students in remote areas to no longer have to rely on poorly trained teachers for their education, as had often been the case. After SchoolNet was installed, schools could be used out of term time as training centres to offer political and educational programmes. As at October 2018, some 1 505 schools were connected to SchoolNet.[4]

Figure 2.2: SchoolNet equipment: the decoder in this case is in a separate room and has the capability only to receive and not to send signals



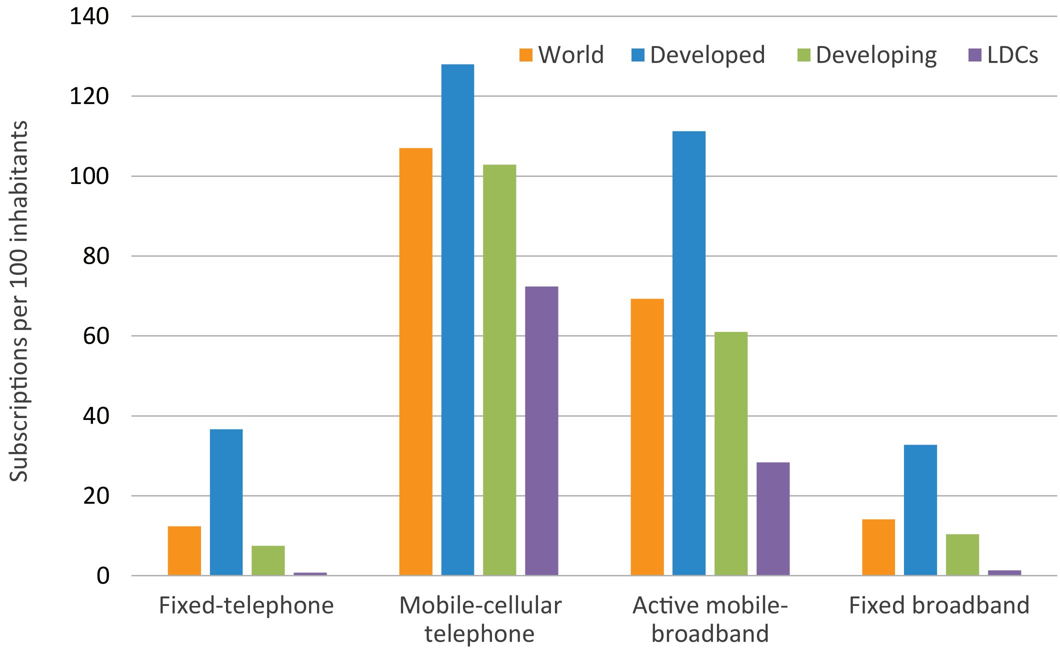
Source: Civic Media Project

1 UN, *WoredaNet - Ehiopian Government Network*, accessed November 2018. Available at http://unpan1.un.org/intradoc/groups/public/documents/un-dpadm/unpan034887.pdf
2 Ministry of Communication and Information Technology, Ethiopia (2018), *Ethiopian Gov't commitment to achieve the 2030 SDGs and the role of ICT (eGovernment)*, 10 October 2018. Available at http://workspace.unpan.org/sites/Internet/Documents/ICT%20to%20SDG%20Ethiopian%20experiance.pptx.pdf
3 Civic Media Project, op. cit.
4 Ministry of Communication and Information Technology, Ethiopia (2018), op. cit.

Given the economic challenges faced by developing countries, access to the opportunities associated with broadband Internet is particularly important. By virtue of its potential for application in diverse sectors of the economy, this technology offers new prospects for the most vulnerable countries to achieve a step change in economic and social development. Thus, failure to ensure high levels of access to and use of broadband may have significant implications for countries that are already vulnerable, with the risk of seeing them fall further behind. In 2017, fixed-broadband subscriptions in LDCs stood at just one per 100 inhabitants, compared to 9.5 in developing countries and 31 in developed countries (Figure 2.3). Active mobile-broadband subscriptions in LDCs exceeded 20 per 100 inhabitants in 2017; but in developing countries and developed countries the corresponding figures were almost 50 and close to 100 per 100 inhabitants, respectively.

It is certainly the case that in developed countries, by the end of the twentieth century, fixed-line telecommunication networks were widespread, with relatively high penetration, in contrast to the situation in many developing countries and LDCs, where fixed infrastructure was often of poor quality and located only in major urban centres. Advances in mobile technology in the 1990s, however, heralded a cheaper form of communications infrastructure which could be rapidly deployed. This change, typically coupled with the privatization of former state-owned telecommunication companies, advances in mobile–cellular technologies and the introduction of competition in ICT markets, brought new mobile services to a huge proportion of previously unconnected populations in developing countries. Further technological advances are now bringing Internet connectivity to these underserved populations, mainly via mobile-broadband services; yet, as previously noted, the LDCs continue to lag behind (Figure 2.3).

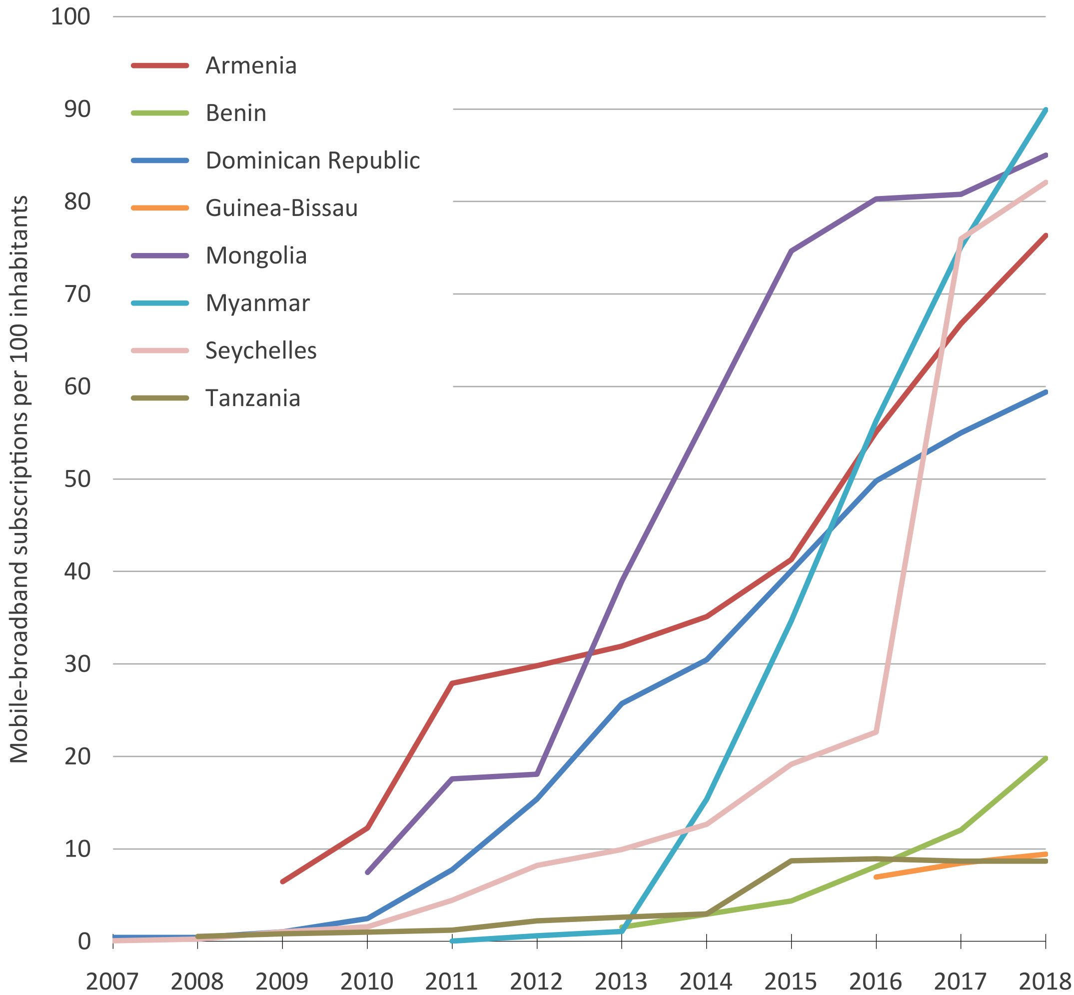
Figure 2.3: ICT penetration by level of development, 2018



Source: ITU

As the market for broadband services continues to evolve rapidly, estimating the long-term economic effects when services are still in their infancy, particularly in low-income countries, is a challenging task. Either sufficient panel data[10] or a relatively long time series are required to estimate the indirect long-term impact of broadband on economic growth. This explains why, to date, there have been few attempts to assess the quantitative impact of broadband services on economic growth in LDCs, LLDCs and SIDS. However, longer-term data for mobile-broadband penetration are now available for many of these countries (Figure 2.4), and broadband services are now well established in many economies (Figure 2.5). As such, the time is ripe to investigate economic impacts using econometric modelling approaches.

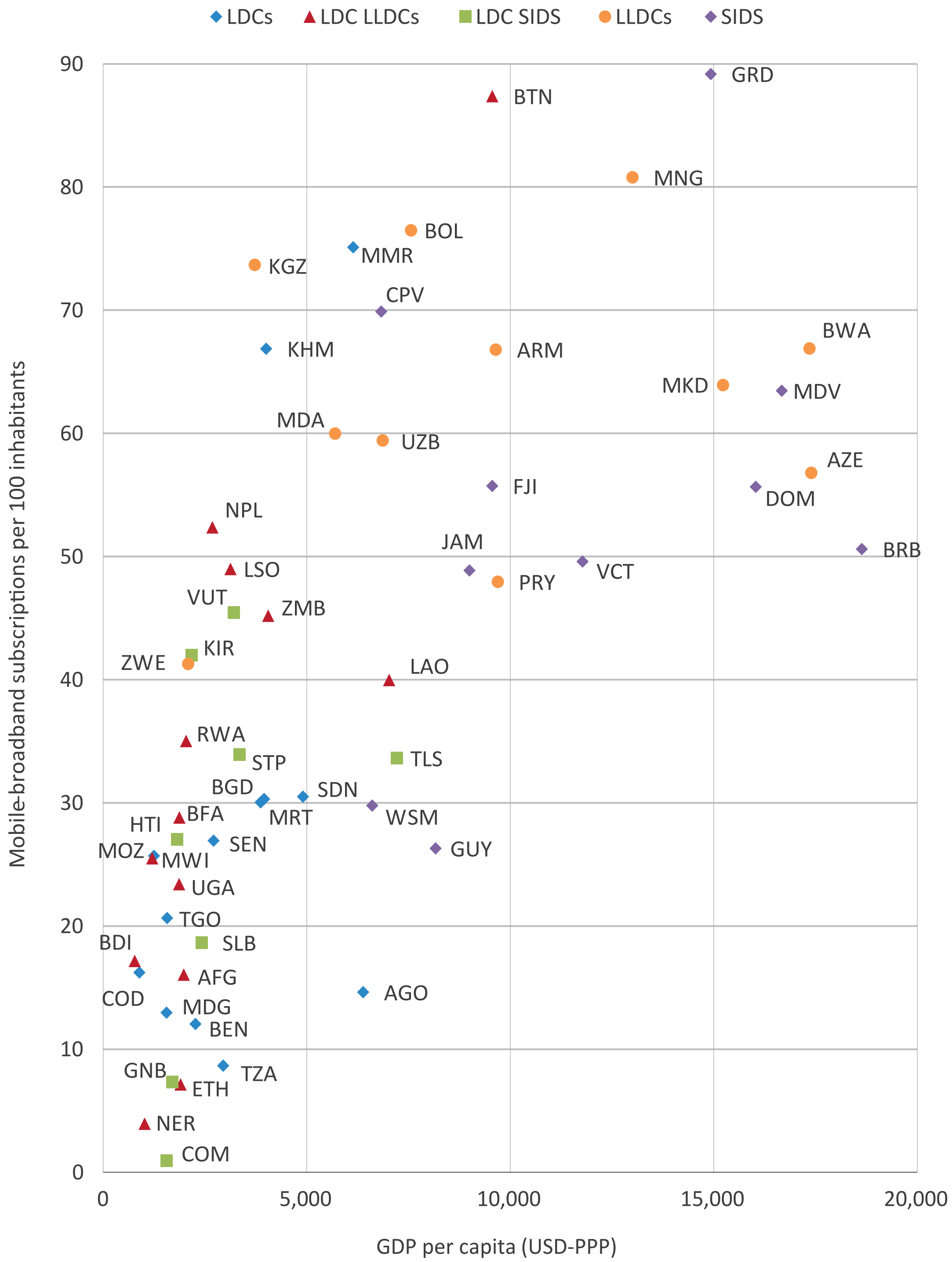
Figure 2.4: Mobile-broadband penetration for a sample of developing countries, 2007 to 2018



Source: ITU

[10] A combination of time-series and cross-sectional data.

Figure 2.5: Mobile-broadband penetration compared to GDP per capita for LDCs, LLDCs and SIDS with GDP per capita less than USD 20 000, 2018



Source: ITU, World Bank

Countries with GDP per capita over USD 20 000 include Bahamas, Bahrain, Kazakhstan, Mauritius, Seychelles, Singapore and Trinidad and Tobago.

2.2 Insights from earlier studies

2.2.1 Background: The economic impact of ICT

As long ago as the 1960s, economists were investigating how telecommunication infrastructure relates to economic growth and productivity. A pioneering study by Jipp (1963) found a positive relationship – now known as the Jipp curve – between telephone density and GDP.[11] Given evidence of a relationship, later studies sought to identify causation. For example, Cronin et al. (1991) examined causality between telecommunication investment and aggregate output with a series of tests on data from the United States over a 31-year period, finding evidence of bidirectional causation.[12] On the one hand, investment in telecommunications may lead to increased economic activity through lower transaction costs, reduced information asymmetries and increased service availability. On the other, as economic output grows, demand for telecommunication services expands, as does the capacity of market participants to invest in telecommunications. Other studies came to similar conclusions following tests on different datasets,[13] although analysis by Dutta in 2001, using time-series (1970–1993) data for both industrialized and developing countries, indicated a stronger effect in the direction of causality from telecommunication infrastructure to economic activity than in the other direction.[14] In other words, the impact of the availability of telecommunication infrastructure on economic growth is stronger than the impact of economic growth on investment in telecommunication infrastructure. However, these research articles focused solely on establishing the association and the direction of causality between telecommunication infrastructure and economic growth, without quantifying the impact.

There is some evidence that the impact of telecommunications on economic output differs according to the level of development of countries. Röller and Waverman (2001) investigated the impact of fixed telecommunications on national income growth in 21 OECD countries from 1970 to 1990, and found that countries with relatively high penetration rates enjoy higher levels of growth compared to those with lower penetration levels. The study estimated that a 10 per cent increase in fixed-telecommunication penetration results in a 2.8 per cent growth effect in GDP, with a penetration rate of 24 subscribers per 100 inhabitants as a critical mass.[15] On the basis of a considerably larger sample of 105 countries, Lam and Shiu (2010) found that the level of development has an impact on causality. A two-way causal relationship between teledensity[16] and national income was observed for European countries, while in general a one-way relationship from national income to teledensity was observed for less-developed countries.[17] However, an analysis by Niebel (2014) examining ICT and rates of GDP growth using subsamples of developing, emerging and developed countries for the period 1995 to 2010 found only very small differences in output elasticities across the three country groupings,[18] suggesting that the level of development may not be particularly relevant in predicting the impact of telecommunications on national income.[19] Given this mixed evidence in the literature, in this study of vulnerable countries, many of which are the LDCs, the potential impact of penetration thresholds is explored.

[11] A. Jipp, "Wealth of nations and telephone density," *Telecommunications Journal* 30 (1963): 199–201.

[12] Francis J. Cronin, Edwin B. Parker, Elisabeth K. Colleran and Mark A. Gold, "Telecommunications infrastructure and economic growth: An analysis of causality," *Telecommunications Policy* 15, no. 6 (December 1991): 529–535

[13] See, for example, Gary Madden and Scott J. Savage, "CEE telecommunications investment and economic growth", *Information Economics and Policy* 10, no. 2 (June 1998): 173–195.

[14] Amitava Dutta, "Telecommunications and economic activity: An analysis of Granger causality", *Journal of Management Information Systems* 17, no. 4 (Spring 2001): 71–95.

[15] Lars-Hendrik Röller and Leonard Waverman, "Telecommunications infrastructure and economic development: A simultaneous approach", *American Economic Review* 91, no. 4 (September 2001): 909–923.

[16] The number of both fixed and mobile subscribers per 100 inhabitants.

[17] Pun-Lee Lam and Alice Shiu, "Economic growth, telecommunications development and productivity growth of the telecommunications sector: Evidence around the world", *Telecommunications Policy* 34, no. 4 (May 2010): 185–199.

[18] Thomas Niebel, *ICT and economic growth – Comparing developing, emerging and developed countries* (Discussion Paper, Centre for European Economic Research, December 2014).

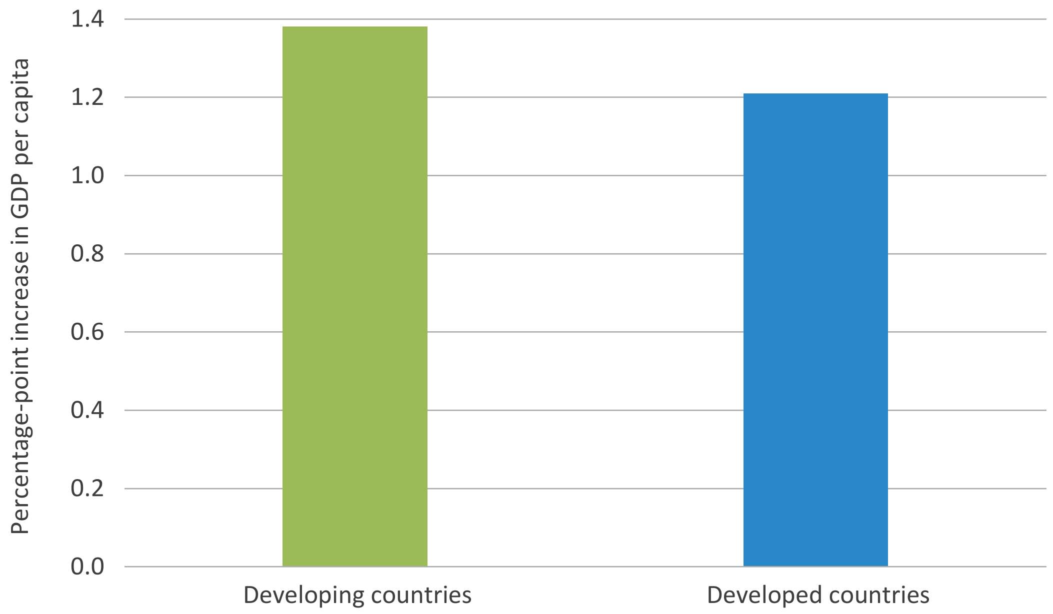
[19] Elasticity is a measurement of the effect of a (small) change in one variable upon another variable. It is defined mathematically as the ratio of the percentage changes of the two variables and is a tool commonly used in econometrics to quantify the impact of various factors on parameters known to be affected by those factors.

2.2.2 The economic impact of broadband

Early empirical studies focused on fixed voice telecommunications. With technological advances, in the twenty-first century the focus shifted to fixed-broadband services, and mobile telephony. A 2009 World Bank study using data from 1980 to 2006 identified positive impacts of mobile and broadband services on GDP in both developed and developing countries. Headline results from this study include:

- for developing countries, a 10 percentage point increase in the number of broadband subscribers leads to a 1.38 percentage point growth in GDP per capita
- for developed countries, the same change leads to a 1.21 percentage point increase in GDP per capita (Figure 2.6).[20]

Figure 2.6: Growth effects of fixed broadband



Source: World Bank, 2009

These results are striking. However, in general, results from subsequent studies have been mixed, and some have even found a perverse relationship[21] or no evidence of a relationship.[22] Furthermore, it is likely that the margin of error is significant in the 2009 study, particularly for developing countries, since the time-series data available a decade ago were extremely limited.

A number of other studies have examined the relationship between fixed broadband and economic growth, and estimated that the economic impact could range from a 0.01 per cent to 1.5 per cent increase in growth of GDP per capita for a 10 per cent increase in fixed-broadband penetration (Figure 2.7). For developing countries, we should place more weight on the results of studies that use the most recent data, which reflect higher uptake than pre-2010 data. Of particular note is a 2018 ITU study which found that for countries with a GDP per capita of between USD 12 000 and USD 22 000, a 10 per cent increase in fixed broadband yields a 0.6 per cent increase in GDP, while a 10 per cent

[20] Christine Zhen-Wei Qiang, Carlo M. Rossotto and Kaoru Kimura, "Economic impacts of broadband", in *Information and Communications for Development 2009* (World Bank, 2009): 35–50.

[21] Herbert G. Thompson and Christopher Garbacz, "Economic Impacts of mobile versus fixed broadband", *Telecommunications Policy* 35, no. 11 (December 2011): 999–1009. The study uses data for 43 countries from 2005 to 2009, finding a positive impact on GDP per household for mobile broadband but a negative impact for fixed broadband.

[22] See, for example, Štefan Bojnec and Imre Fertő, "Broadband availability and economic growth", *Industrial management and data systems* 112, no. 9 (2012): 1292–1306. The study investigates alternative model specifications for 34 OECD countries for 1998 to 2009.

increase in mobile broadband yields a 1.8 per cent increase in GDP. For lower-income countries (GDP per capita less than USD 12 000), a 10 per cent increase in mobile broadband yields an even higher increase in GDP of 2 per cent.[23]

Figure 2.7: Economic impact of fixed broadband – empirical findings

10 per cent increase in fixed-broadband penetration
→ increase in GDP
- **0.8 per cent**

10 per cent increase in mobile-broadband penetration
→ increase in GDP
- **1.5 per cent**

ITU (2018)
Full sample of 139 developed and developing countries
2010-2017 quarterly data

One-time effect in the year fixed-broadband was introduced→ increase in growth of GDP/capita
- **3.06 percentage points**

Thereafter 10 per cent increase in fixed-broadband
→ annual increase in growth of GDP/capita
- **0.01 percentage points**

Candelaria (2015)
35 developed and developing countries
1981-2013 annual data

One-time effect in the year fixed-broadband was introduced
→ increase in GDP/capita
- **2.7 to 3.9 per cent**

Thereafter 10 percentage point increase in fixed-broadband penetration
→ increase in growth of GDP/capita
- **0.01 percentage points**

Czemich et al (2011)
20-25 OECD countries
1996-2007 annual data

10 percentage point increase in fixed-broadband penetration
→ increase in growth of GDP/capita
- **1.21 percentage points** (high-income countries)
- **1.38 percentage points** (low- and middle-income countries)

World Bank (2009)
120 countries
1980-2006 annual data

[23] ITU, "The economic contribution of broadband, digitization and ICT regulation", ITU expert report, 2018.

Two studies by Koutrompis (2009 and 2018) find a positive relationship between fixed-broadband uptake and national income growth in OECD countries.[24] The earlier (2009) study uses European Union (EU) data from 2002 to 2007, while the later (2018) study covers a much longer time period, from 2002 to 2016. The earlier study found empirical support for a critical mass effect, whereby countries with lower broadband penetration levels (less than 20 per cent penetration in 2006) experienced on average a lower annual impact on economic growth (0.15 per cent) than countries with medium penetration (0.23 per cent for countries with 20-30 per cent penetration) and high penetration (0.39 per cent for countries with over 30 per cent penetration). Other studies have also found increasing returns to scale in relation to the level of broadband adoption. For example, Gruber et al. (2014), using data for 27 EU countries from 2005 to 2011, compare model results for subsamples of countries below and above a 15 per cent broadband uptake threshold, finding an annual impact of broadband on GDP almost 0.2 per cent greater in the higher uptake sample compared to the lower uptake group.[25]

Analysis from the later Koutrompis study finds on average an annual 0.3 per cent impact of broadband on GDP, but also indicates that results differ according to both the rate and level of broadband adoption. The study indicates that there is a critical threshold, beyond which the marginal effect declines as higher connectivity is achieved:

- an increase from 10 to 20 connections per 100 inhabitants leads to a 1.4 per cent increase in GDP
- an increase from 20 to 30 connections per 100 inhabitants leads to a 0.82 per cent increase in GDP.

The later Koutrompis analysis also considers the impact of increasing broadband speed from 2 Mbit/s to 8 Mbit/s, and finds that this boosts GDP by a further 0.9 per cent. Moreover, sample countries with lower average broadband speeds experienced a lower GDP impact than countries with higher average speeds over the study time period. Results from other studies also indicate that the speed of the broadband connection is important for economic growth and development. Kongaut and Bohlin (2014), using a sample of OECD countries from 2008 to 2012, find that a 10 per cent increase in broadband speed leads to a 0.8 per cent increase in GDP per capita.[26] When the sample is restricted to the lower-income OECD countries only, the result is higher, implying that the quality and speed of the connection really does matter in countries with lower income.

The direction of causality between broadband penetration and economic growth has been investigated by Arvin and Pradhan using G20 countries over the period 1998 to 2011. The study finds a short-run bidirectional causality only for the wealthier sample countries, while for the other countries a one-way causality runs from economic growth to broadband penetration. In the long run, the analysis does not support any causal link for either sample grouping.[27]

To date, very few studies have examined the impact of mobile-broadband on economic growth and development. Nevertheless quantifiable economic effects are emerging in countries such as Kazakhstan, where, supported by both fixed and mobile-broadband services, e-commerce continues to expand, generating additional revenue and employment. Edquist et al. (2017) do explore the relationship between mobile-broadband and economic growth using several alternative model specifications and data from 130 countries over the period 2002 to 2014. Their study finds that a

[24] Pantelis Koutrompis, "The economic impact of broadband on growth: A simultaneous approach", *Telecommunications Policy* 33, no. 9 (October 2009): 471–485; Pantelis Koutrompis, *The economic impact of broadband: Evidence from OECD countries*, April 2018.

[25] Harald Gruber, Jussi Hätönen and Pantelis Koutrompis, "Broadband access in the EU: An assessment of future economic benefits", *Telecommunications Policy* 38, no. 11 (December 2014): 1046–1058.

[26] Chatchai Kongaut and Erik Bohlin, *Impact of broadband speed on economic outputs: An empirical study of OECD countries* (Conference Paper, 25th European Regional Conference of the International Telecommunications Society (ITS), Brussels, Belgium, June 2014).

[27] B. Mak Arvin and Rudra P. Pradhan, "Broadband penetration and economic growth nexus: Evidence from cross-country panel data", *Applied Economics* 46, no. 35 (2014): 4360–4369.

10 per cent increase in mobile-broadband penetration leads to an increase in GDP of between 0.6 and 2.8 per cent, depending on the model specification.[28]

Kazakhstan – E-commerce

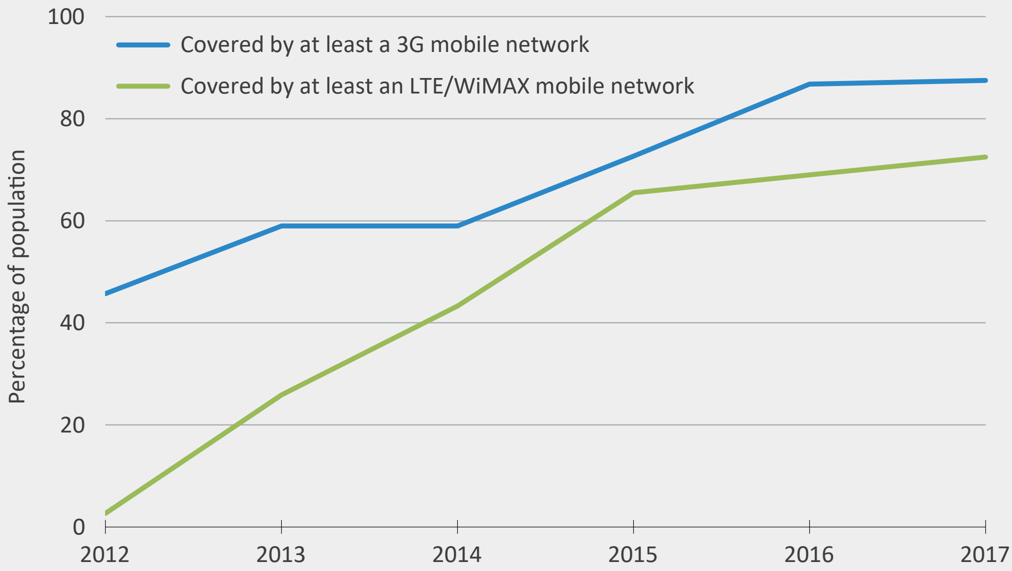
The Kazakhstan government aspires to elevate standards of living in the country through the use of digital technologies, and to this end has commenced the programme Digital Kazakhstan.[1] The programme is to be carried out during the period 2018 to 2022, with five key themes:

- Digitization of branches of the economy – using technologies to increase labour productivity
- Transition to the digital State – transformation of State infrastructure
- Implementation of the digital Silk Road – development of high-speed and secure broadband infrastructure
- Evolution of human capital assets – moving towards a knowledge-based economy

Establishment of an innovative ecosystem – fostering technological entrepreneurship.

Mobile-broadband availability in Kazakhstan has been increasing since 2012, and by 2017 some 87 per cent of the population was covered by at least a 3G mobile network, and 72 per cent by an LTE/WiMAX network (Figure 2.8).

Figure 2.8: Availability of mobile broadband in Kazakhstan, 2012 to 2017



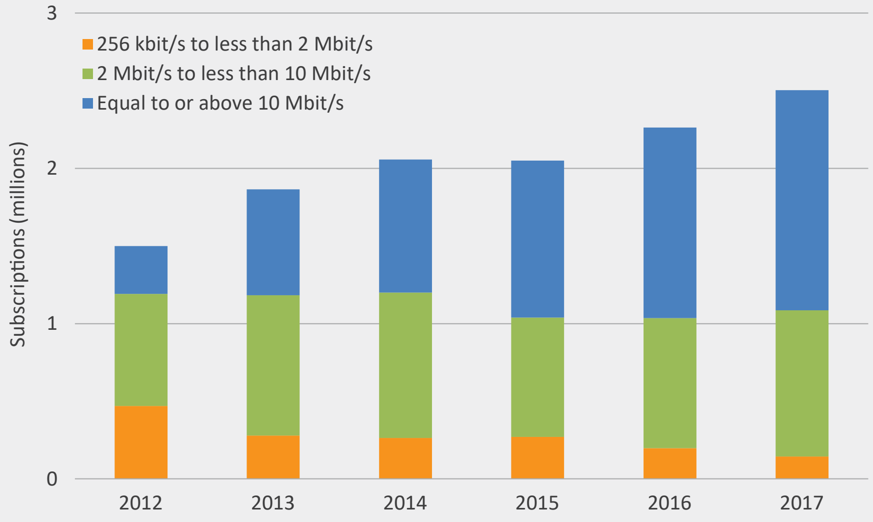
Source: ITU

[1] Digital Kazakhstan, *The programme "Digital Kazakhstan"*, accessed November 2018. Available at https://digitalkz.kz/en/.

[28] Harald Edquist, Peter Goodridge, Jonathan Haskel, Xuan Li and Edward Lindquist, *How important are mobile broadband networks for global economic development?* (Discussion Paper 2017/05, Imperial College Business School, 24 May 2017).

Fixed-broadband subscription speeds in Kazakhstan have been increasing since 2012, as shown in Figure 2.9.

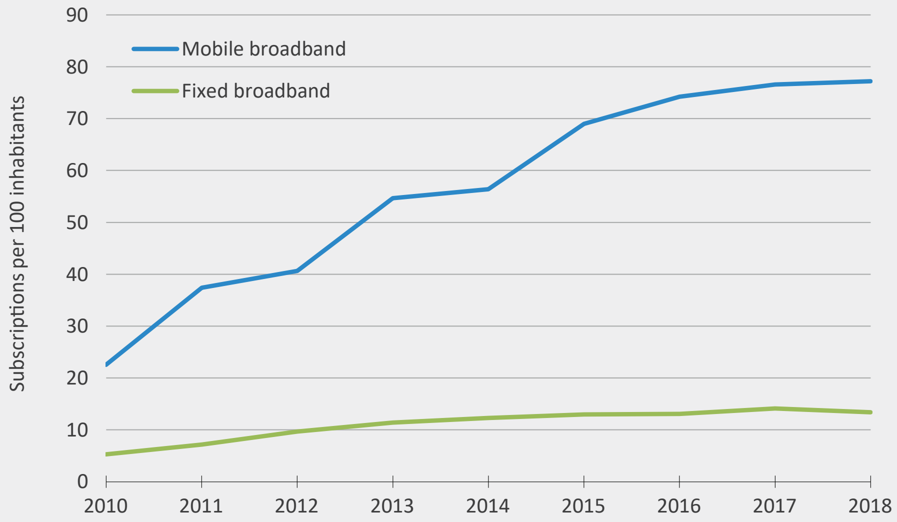
Figure 2.9: Fixed-broadband subscriptions in Kazakhstan by speed, 2012 to 2017



Source: ITU

Uptake of both mobile- and fixed-broadband services in Kazakhstan has been increasing since 2010. By 2018, there were 77 mobile- and 14 fixed-broadband subscriptions per 100 inhabitants (Figure 2.10).

Figure 2.10: Fixed- and mobile-broadband telepenetration in Kazakhstan, 2010 to 2018



Source: ITU

In 2017, e-commerce market turnover came to KZT 106.9 billion (USD 980 million), 1.2 per cent of total retail turnover, which represented a 36.2 per cent increase on the previous year.

E-commerce turnover in the first five months of 2018 stood at KZT 101 billion (USD 926 million), 2.9 per cent of total retail trade turnover. No fewer than 110 new e-commerce retailers were registered during this time. There are now 1 658 online stores operating, employing 71 600 workers.

The government has undertaken a number of measures aimed at boosting electronic commerce, including:

- legislation, with the Ministry of National Economy having drafted a bill “On Amendments to Certain Legislative Acts of the Republic of Kazakhstan on Trade Regulation” to provide a mechanism for the regulation of e-commerce
- development of digital financial services, with the National Bank developing a draft online instant payment system
- upgrade of the postal service to improve delivery time of parcels
- tax exemptions for e-commerce companies.[1]

One notable e-commerce success story from Kazakhstan is Chocofamily, which launched in 2011 with a daily deal service, Chocodaily. Two years later, the company expanded into food-delivery and ticket-search services. In 2014, the company employed 150 people, with 1 million purchases made on the site. By 2018, this had increased to 350 employees, with 2 million registered users making 7 000 purchases per day. Turnover in 2017 increased from KZT 11 billion (USD 101 million) to over KZT 18 billion (USD 165 million).[2] In 2018, the company expects turnover of KZT 55 billion (USD 504 million).[3] The Chocofamily structure is the largest e-commerce holding in Kazakhstan, and includes six companies:

- Chocolife.me – collective purchase coupon services, similar to Groupon
- Chocotravel.com – online travel service
- Chocomart.kz – online shopping
- Lensmark.kz – online shop for contact lenses
- Chocofood.kz – food-delivery service
- iDoctor.kz – services to find doctors.

Chocofood has an 80 per cent market share in the food-delivery market, serving 34 000 orders per month and working with 350 restaurants. Chocotravel sells 80 000 air tickets and 50 000 railway tickets per month.

The company also launched a payment app, Ramket, in 2017, which allows users to pay for purchases by scanning QR codes and can be linked to users’ bank cards.[4]

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1 Government of the Republic of Kazakhstan (2018), *Government discusses e-commerce development*, 5 June 2018. Available at http://www.government.kz/en/novosti/1014836-government-discusses-e-commerce-development.html

2 Informburo (2018), *Kazakhstan selected the best business leaders. Who is on the list?*, 26 September 2018. Available at https://informburo.kz/stati/v-kazakhstane-vybrali-luchshih-rukovoditeley-kto-v-spiske.html

3 Profit.kz (2018), *Chocofamily attracted 350 million tenge for the development of a new project “Rakhmet”*, 19 July 2018. Available at https://profit.kz/news/48501/Chocofamily-privlek-350-mln-tenge-na-razvitie-novogo-proekta-Rahmet/

4 Techcrunch, *How this Kazakhstan Internet giant built success on ideas from Russia and China*, accessed November 2018. Available at https://techcrunch.com/2018/10/11/how-this-kazakhstan-internet-giant-built-success-on-ideas-from-russia-and-china/

The 2018 ITU study uses a simultaneous equation model with quarterly data for developed and developing countries from 2010 to 2017, and finds a greater economic impact of mobile broadband in low-income countries compared to higher-income countries.[29] However, as already demonstrated in Figure 2.3, in LDCs mobile-broadband penetration is substantially higher than fixed-broadband penetration. As levels of mobile-broadband penetration increase, so too do opportunities for LDC governments to introduce new services and applications to improve economic and social circumstances. As an example, in Bhutan, an LLDC with a mobile penetration of 68 per 100 inhabitants, e-government initiatives are offering cost savings to both businesses and citizens, although it is difficult at this stage to assign a monetary value to these.

29 ITU (2018), op. cit.

Bhutan – E-government

A prime example of cost savings for businesses is that they no longer have to go to the Trade Office to apply for or renew their business licences. The government now offers 34 government-to-business (G2B) services, such as application for or renewal of retail and wholesale trade licences, application for trade and import house registration and application for cottage and small-scale industry licences.

Citizens are also able to save time and money through access to 49 government-to-citizen (G2C) services which are now available online (Kuensel). These services include passport applications, judicial services, applying for educational scholarships and job searches (Figure 2.11).[1] In 2017, e-payment for G2C services was launched for four different agencies. Citizens can now pay online for services offered by these four agencies. This includes paying passport fees and renewal fees for driving licences or penalties.[2]

Figure 2.11: Bhutan's site for G2C services

Source: Royal Government of Bhutan

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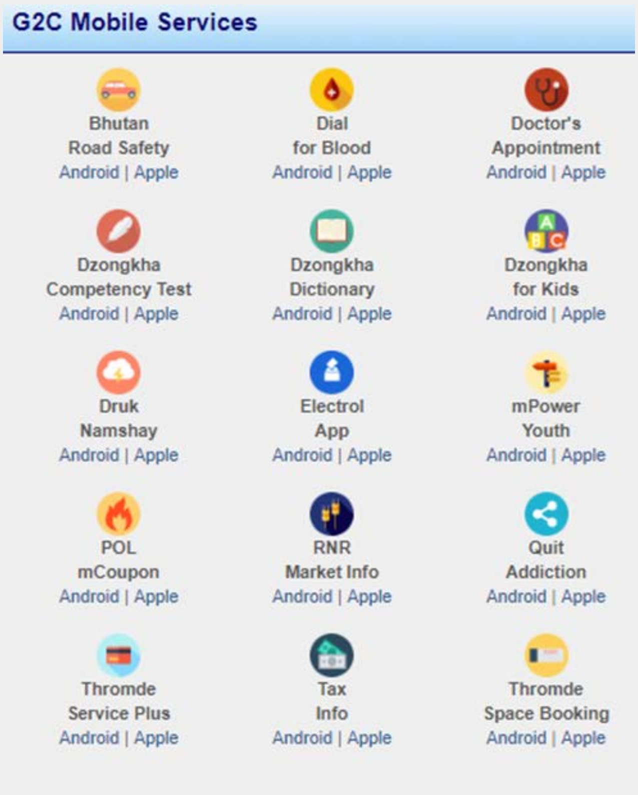
[1] Royal Government of Bhutan, *G2C eServices*, accessed November 2018. Available at https://www.citizenservices.gov.bt

[2] Kuensel (2018), *Six more G2C services go online*, 15 June 15 2018. Available at http://www.kuenselonline.com/six-more-g2c-services-go-online/

The G2C app offers 15 services in mobile app form (Figure 2.12). These services, provided through specific apps available for both Android and iPhone, include, for instance, making a doctor's appointment, obtaining tax information, accessing market information and improving literacy through a dictionary in app form.

Figure 2.12: Bhutan's G2C mobile services



Source: Royal Government of Bhutan

2.3 Main challenges

2.3.1 Selecting the sample

The scope of this study covers LDCs, LLDCs and SIDS, which comprise 91 countries in total, over the period 2000 to 2017. Because these vulnerable countries often do not have sufficient resources for data collection, economic data may be incomplete, of poor quality or non-existent. The sample has, of necessity, been restricted to those countries for which reliable data are available over part or all of the required period.

The sample size – along with the sizes of the separate subsamples of LDCs, LLDCs and SIDS – has influenced the nature of the econometric analysis in this study. The sample (or any subsamples that are considered) must have sufficient observations to support the selected methodology as well as the number of explanatory variables used within the resultant models.

Data for certain variables in many of these countries are not available. For example, one key variable – investment in broadband – is missing for most LDCs and LLDCs, and thus could not be used in the analysis.

The two resultant samples consisted of 47 and 62 countries out of 91, for assessing the effect of fixed-broadband and mobile-broadband penetration, respectively (Table 2.1).

Table 2.1: Model samples

Model	Number of countries	Observations
Fixed broadband	47	511
LDCs	23	197
LLDCs	28	306
SIDS	14	153
Mobile broadband	62	329
LDCs	37	175
LLDCs	29	168
SIDS	15	73

Data availability was the main factor that limited the sample size. In particular, many of the countries within the sample had little or no data for the following indicators:

- typical fixed-broadband speeds
- Internet subscriptions per 100 inhabitants
- fixed wireless broadband subscriptions per 100 inhabitants
- coverage of 3G and LTE mobile networks
- fixed capital formation
- annual usage of international Internet capacity.

2.3.2 Selecting an appropriate modelling approach

Three main econometric approaches for estimating the impact of ICT or broadband on economic output may be discerned from the literature:

- *Ordinary least squares* (OLS): This method uses the least squares principle to fit a pre-specified regression through the sample data. While this method may establish an association between GDP and broadband penetration such that the one can be used to estimate the other, it does not establish the direction of causation.
- *Instrumental variables* (IV): This method is used to address the problem of reverse causality or endogeneity. It is based on the assumption that the variable of interest, such as broadband penetration, is being facilitated by an external variable, such as fixed-telephone line penetration. This external variable may be used as an “instrument”. In the first stage, an OLS regression is used to predict broadband penetration using the instrumental variable. The predicted values are used in a second OLS regression to predict the value of the economic output, such as GDP per capita. If the chosen instrumental variable is not correlated with the economic output, this method also establishes causal relationships.
- *Simultaneous equations model* (SEM): In this method, causality is determined by solving a set of two or more regression equations simultaneously, where left-hand side variables are among

the right-hand side variables of other SEM equations. As the system of equations exhibits some sort of back and forth causation between right-hand and left-hand variables, the simultaneous solution determines the causality between the economic outcome and the variable of interest.

In essence, the various approaches apply differing model specifications to the data. It is worth noting that a number of studies employ more than one model specification in order to compare results.

Ordinary least squares

Some studies apply pooled OLS (POLS) statistical techniques, often encompassing either fixed effects (FE) or random effects (RE).[30] Examples include Niebel (2014) and Edquist et al. (2017), although in both cases IV models (see below) are tested in addition.[31] One of the main issues with the use of OLS is that it is not able to accommodate any solution for potential two-way causality. Consequently, there has been a strong trend in the literature towards developing models using two-stage least squares (2SLS),[32] three-stage least squares (3SLS) or simultaneous equations. Such models encompass a number of different economic relationships, which is not possible in the simple single-equation OLS model.

The World Bank study[33] used OLS in a cross-sectional endogenous growth model, based on Barro.[34] The Barro approach examines long-term average growth rates, which would be less subject to issues associated with missing or poor-quality data – problems that are fairly typical in many developing countries. In fact, the authors state that they used this approach to avoid annual data and the associated problems caused by missing data or errors.[35] As already noted, the use of OLS does not address potential reverse causality issues. However, the authors concluded, after performing a Hausman test, that the null hypothesis of OLS being efficient could not be rejected – in other words, that there was no failure of the OLS model due to endogenous variables.[36]

Instrumental variables

A number of studies adopt IVs to address potential endogeneity bias, caused when an explanatory variable (such as fixed broadband) is correlated with the dependent variable (income, which is typically represented by the proxy of GDP per capita), thereby introducing a correlation with the error term. Accordingly, in this approach instruments are used which are correlated with the explanatory variable but not with the error term. As an example, Czernich et al. (2011) use telecommunication access lines and cable television subscriptions as instruments on the basis that access to existing relevant infrastructure is a prerequisite for the deployment of economically viable fixed-broadband infrastructure.[37] For mobile broadband, Edquist et al. (2017) use mobile subscriptions and fixed-Internet users as instruments on the grounds that these are predeterminants of the likely diffusion of mobile-broadband services.[38]

Simultaneous equations

With the aim of addressing the issue of reverse causality, Röller and Waverman (2001) developed a simultaneous equation model.[39] This approach was adopted in a number of subsequent studies,

30 An FE model controls for country-specific effects while an RE model assumes cross-country variation is random. Note that there are alternative techniques available for implementing these approaches.

31 Niebel, op. cit.; Edquist et al., op. cit.

32 See, for example, Thompson and Garbacz, op.cit.

33 Qiang et al., op. cit..

34 Robert J. Barro, "Economic growth in a cross-section of countries", *The Quarterly Journal of Economics* 106, no. 2 (May 1991): 407–443.

35 Qiang et al., op.cit.

36 Ibid.

37 Nina Czernich, Oliver Falck, Tobias Kretschmer and Ludger Woessmann, "Broadband infrastructure and economic growth", *The Economic Journal* 121, no. 552 (May 2011): 505–532.

38 Edquist et al., op.cit.

39 Röller and Waverman, op.cit.

including Koutrompis (2009 and 2018), Gruber et al. (2014) and Alderete (2017).[40] The basic model consists of separate equations linked via common variables, with those equations representing:

- an aggregate production function
- demand for ICT/broadband
- supply of ICT/broadband
- output of ICT/broadband.

In this approach, ICT/broadband is effectively endogenous, and can be estimated simultaneously with the economy-wide production function.

Which approach is optimal?

So, which modelling approach delivers the most robust results? It is difficult, when comparing models based on alternative methodologies, to determine which might be the "best" model. Use of differing dependent and explanatory variables means that a direct comparison of the reported diagnostics (R^2, t statistics) is often inappropriate. In some instances, authors do not report standard errors of the model parameters, or of the estimates. Hence, in these cases, it is impossible to determine the level of uncertainty associated with the model in question and compare this with other models.

In terms of the most recent studies, there are a number of examples of POLS, IV and simultaneous equations. For example, Edquist et al. (2017) achieve robust results for both pooled OLS/FE and the IV approach.[41] At the same time, in general, studies based on simultaneous equations have met with considerable success. Therefore, this latter approach continues to be applied in contemporary literature, driven by its success in addressing the potential endogeneity issues characteristic of modelling the relationship between ICT and income.

The main challenge in the application of the simultaneous equation method for developing countries is assembling a complete dataset.[42] This was indeed the problem identified with the sample countries for this study – there are insufficient economic data available to support a simultaneous equation model.

Consequently, in addition to pursuing best-practice econometric techniques, it is also necessary to adopt a pragmatic approach in the light of the available data. Therefore, while the original intention was to explore the three types of approaches, due to data limitations only OLS and IV approaches are employed.

40 Koutrompis (2009), op. cit.; Koutrompis (2018), op. cit.; Gruber et al., op. cit.; María Verónica Alderete, "An approach to the broadband effect on Latin American growth: A structural model", *Cuadernos de Economía* 36, no. 71 (2017): 549–569.

41 Edquist et al., op. cit.

42 An earlier ITU study indicates that the simultaneous equation approach is preferable for the reasons discussed, but finds insufficient time-series data for pricing and competition for the Latin American sample countries. See ITU, *Impact of broadband on the economy*, April 2012, p.30.

3 Approach

3.1 Scope

The modelling analysis is conducted for the time period 2000 to 2017. Data from before 2000 are not included, given the limited availability of broadband in low- and middle-income economies prior to the turn of the century. A number of economic, telecommunication and demographic variables were considered in the analysis, including all those previously identified in the literature as statistically significant or likely to be significant. These variables are discussed in Section 3.3.

The full dataset comprised countries listed in Section 1.1 for which data were available. The analysis is conducted on the whole sample – excluding those observations with missing values – with the introduction of dummy variables to capture LDCs, LLDCs and SIDS.

3.2 Overview of the methodology

The study approach comprises the following steps:

- data collection
- model development
- comparison of models.

Data collection

Raw data required for the key variables (Section 3.3) for the relevant countries were collected from several data sources, including:

- ITU – World Telecommunication/ICT Indicators Database
- United Nations – UNdata
- World Bank – World Development Indicators
- ILO – ILOSTAT.

The raw data were processed to identify observations with missing data, as well as to adjust or remove poor-quality data, and calculate other variables from the raw data.

Model development

For the entire sample, various approaches were investigated, exploring different functional forms, estimation methodologies and variables. Preliminary analysis revealed that a simultaneous equation model cannot be applied due to a lack of data for relevant variables for the countries within the dataset.

The choice of independent variables for regression analysis was guided by the existing literature. A stepwise approach for the selection of variables was used in the OLS analyses. This is an iterative procedure in which a variable is added (or removed) from the model based on diagnostic criteria, typically associated with improvements of the fit of the model to the data. This process continues until there is no statistically significant improvement in the model from the addition (or removal) of any variable. Independent variables found to be statistically significant during the OLS analysis were later used to build the IV regression model.

Model forms, for both OLS and IV, were established and implemented in the statistical programming language *R*. Diagnostic output was examined to determine the suitability of the model form – the aim being to identify a model which satisfactorily explains the observed variation in the sample data of the dependent variable.

The original intention of this study was to undertake separate analyses for the subsamples of LDCs, LLDCs and SIDS, but there are insufficient data for some subsamples to support this level of analysis. As a result, data across the subsamples were pooled, and dummy variables were employed to identify statistically significant differences in behaviour of the groups.

3.3 Key variables

Dependent variable

Research on the impact of broadband on the economy has used several measures of economic activity as the dependent variable. These include:

- GDP
- GDP per capita
- GDP per household
- growth of GDP.

These measures have yielded regressions with varying degrees of explanatory power. From the literature, it appears that models using growth of GDP as a dependent variable are the least successful.

Many studies use measures of aggregate economic output as the dependent variable. While GDP may not represent a perfect reflection of welfare, it remains the most common measure adopted in research of this kind. GDP is used in studies by Koutrompis (2009 and 2018), Lam and Shiu (2010), Gruber et al. (2014) and others.[43] Edquist et al. (2017) use real value added.[44]

A number of studies have used GDP per capita as the dependent variable. For example, Candelaria (2015) examines the impact on GDP per capita of fixed broadband for 35 countries over the period 1981 to 2013. Czernich et al. (2011) also use GDP per capita for OECD countries from 1996 to 2007 as the dependent variable. Both models obtain statistically robust results.[45]

Use of GDP per household as the dependent variable is less common. Indeed, economic data on a per-household basis are not typically produced by most national statistics offices and it would thus be difficult to obtain sufficient information for cross-country analyses. An attempt by Thompson and Garbacz (2011) produced some counterintuitive results.[46]

The World Bank (2009) study used average annual growth in GDP per capita as its dependent variable.[47] In the context of the present study for developing countries, with the use of averages over a long period, where increased telecoms uptake is restricted to only a portion of the relevant time period, the average penetration rate will not be indicative of the current state of telecoms take-up or investment.

Following a review of the existing literature, as summarized above, the dependent variable selected for the analysis is real GDP per capita, expressed in USD (based on PPP rates).

Independent variables

Careful selection of independent variables – variables used within the model equations to estimate the value of the dependent variable – is important, since the model will be misspecified if relevant variables

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[43] Koutrompis (2009), op. cit.; Koutrompis (2018), op. cit.; Lam and Shiu, op. cit.; Gruber et al., op. cit..

[44] Edquist et al., op. cit.

[45] José Alberto Candelaria, *A panel data analysis of temporary and permanent effects of fixed broadband penetration over economic growth* (2015 Regional ITS Conference, Los Angeles, October 2015); Czernich et al., op. cit.

[46] Thompson and Garbacz, op. cit..

[47] Qiang et al., op. cit.

are omitted or irrelevant variables are included. Omission of relevant variables may lead to biased coefficients, while the inclusion of irrelevant variables may increase standard errors of the estimates.

In addition to ICT penetration and usage, key determinants of GDP per capita are likely to include economic variables such as domestic investment, level of education and participation in the labour force. Earlier studies have explored the impact of these variables using a variety of indicators:

- ICT
  - mobile-broadband subscriptions as a percentage of total connections
  - number of years since the introduction of mobile broadband
  - mobile-cellular subscriptions per 100 inhabitants
  - Internet users per 100 inhabitants
  - broadband subscriptions per 100 inhabitants
- economic
  - gross fixed capital formation, expressed as a percentage of GDP
  - Foreign direct investment (FDI)
- education
  - primary school gross enrolment ratio
  - average years of schooling
- labour force
  - persons engaged in the labour force
  - annual growth in the labour force
  - labour force participation
- demographic
  - level of urbanization.

Capital formation has been found to be a positive significant predictor for GDP growth in the reviewed literature, in a number of studies including Candelaria (2015), Czernich et al. (2011) and Koutrompis (2018).[48] While it is understandably expected that GDP growth leads to more investment in assets and goods, it is also expected that investments in industrial assets, vehicles and productivity-enhancing equipment such as computers will increase labour productivity.

Labour force participation and education level are also expected to have a positive association with GDP per capita. Statistically significant relationships were determined in the studies by Edquist et al. (2017) and Koutrompis (2018). However, in other studies such as Czernich et al. (2011), no significant association was found.[49] The quality and skills of human capital are expected to have a positive impact on GDP, as skilled labour would be more capable of exploiting technological innovations and using resources more efficiently. An empirical study conducted by Hanushek and Woessmann (2008) established a strong relationship between cognitive skills, individual earnings and economic growth.[50] While data on specific skills are largely missing in developing countries, a suitable proxy is the average number of schooling years.

48 Candelaria, op. cit.; Czernich et al., op. cit.; Koutrompis (2018), op. cit.

49 Edquist et al., op. cit.; Koutrompis (2018), op. cit.; Czernich et al., op. cit.

50 Eric. A. Hanushek and Ludger Woessmann, "The role of cognitive skills in economic development", *Journal of Economic Literature* 46:3 (2008),: 607-668.

The level of urbanization, represented by the proportion of the population living in areas with more than 500 inhabitants per square kilometre, was used by Koutrompis (2018). While this variable was found to be statistically significant, the results were found to be counterintuitive as the model predicted a negative association with broadband penetration. This was attributed to the lack of a common standard for defining the level of urbanization across countries.[51]

Instruments

Instruments predicting the diffusion of fixed and mobile broadband are indicators of the required enabling infrastructure or the adoption of related technology among the population. Instrumental variables that have been used in the literature include:[52]

- fixed-telephone network penetration
- cable-TV penetration
- mobile-phone subscriptions per 100 inhabitants
- fixed-Internet users per 100 inhabitants.

For these instruments to be valid, either they have to be unrelated to the dependent variable or their effect has to have diminished compared to the effect of broadband. While it is theoretically possible to use instruments for other independent variables, this is not necessary as only the causality between the dependent variable of interest and broadband penetration needs to be investigated.

3.4 Model specifications

The model specifications in this study – for the fixed-broadband model and the mobile-broadband model – are guided mainly by the work of Czernich et al. (2011).

3.4.1 Fixed-broadband model specification

While fixed-broadband penetration can affect GDP per capita, conversely it can also be related to the economic ability of the society. To establish the direction of causation, an instrument was used to predict fixed-broadband penetration independent of GDP per capita. As instrumental variables, Czernich et al. (2011) used fixed-telephone and TV-network penetration. These variables were shown to sufficiently predict broadband penetration and lead to statistically robust results.[53] However, data for TV-network subscriptions are largely unavailable for developing countries. While Candelaria (2015) and Edquist et al. (2017) also used Internet subscriptions as an instrumental variable,[54] data exploration identified that such data are not available for the most recent four years for LDCs, which would result in a substantially reduced dataset. On account of these limitations, only fixed-telephone penetration was used as an instrument to predict fixed-broadband penetration in this study. This approach builds on the assumption that most fixed-broadband services for the countries within the dataset use DSL technology, which in turn is based on the pre-existing voice-telephony network. The approach assumes that the economic impact of the fixed-telephone network has already diminished due to the introduction of substitutes such as cellular telephony and VoIP telephony. Similarly to Czernich et al. (2011), the second-stage regression of GDP per capita used the following independent variables:

- fixed-broadband subscribers per 100 inhabitants
- fixed capital formation as a percentage of GDP
- average number of years of schooling

51 Koutrompis (2018), op. cit.
52 Czernich et al., op. cit.; Edquist et al, op. cit.
53 Czernich et al., op. cit.
54 Candelaria, op. cit.; Edquist et al, op. cit.

- labour force participation growth rate.

3.4.2 Mobile-broadband model specification

As with fixed broadband, the adoption of mobile broadband can have a bidirectional causal relationship with GDP per capita. To establish causality, an instrumental variable was used to estimate mobile-broadband penetration. For predicting the diffusion of mobile broadband, Edquist et al. (2017) suggested the use of mobile-phone penetration.[55] However, preliminary analysis indicated that this was a poor predictor for mobile-broadband penetration within the sample data. Firstly, one issue is that a person can have more than one subscription, and indeed this is fairly common in countries that have differential on-net and off-net tariffs or where consumers seek to reap maximum benefit from dynamic pricing.[56] Thus, mobile penetration may not accurately represent the proportion of the population using mobile services. Secondly, 2G technology – which does not deliver a mobile-broadband service – is still extensively used in the sample countries.

- mobile-broadband subscribers per 100 inhabitants
- fixed capital formation as a percentage of GDP
- average number of years of schooling
- labour force participation growth rate
- a dummy variable for SIDS.

Although the sample was not able to sustain separate analyses of LDCs, LLDCs and SIDS subsamples, the use of dummy variables denoting each subgroup was explored. Only the SIDS dummy was found to be significant within the analysis.

[55] Edquist et al, op. cit.

[56] Dynamic pricing is a flexible tariffing strategy used by some mobile operators in which tariffs are set in response to market demand.

4 Main findings

Separate models were evaluated, considering the impact of either fixed-broadband penetration or mobile-broadband penetration on the level of GDP per capita. The estimation was carried out by pooling the full sample of countries. As noted in the previous section, there were insufficient data to support separate analyses for subsamples for LDCs, LLDCs and SIDS.

4.1 Fixed-broadband

GDP per capita was selected as the dependent variable, the independent variables being:

- fixed-broadband penetration (*FBBpen*)
- the square of fixed-broadband penetration (*FBBpen*^{2})
- fixed capital formation as a percentage of GDP (*FCFpGDP*)
- average years of schooling (*School*)
- percentage change in labour force participation (*ΔLFP*).

Additionally, one instrumental variable was used to predict the fixed-broadband penetration: fixed-telephone network penetration (*FLpen*).

The square of fixed-broadband penetration was also included to capture a potential nonlinear relationship between the level of GDP per capita and broadband penetration.

Stepwise linear regression

The results of the stepwise linear regression model are shown in Table 4.1. Fixed-broadband penetration, average years of schooling and fixed capital formation show a strong association with GDP per capita at a significance level of 99.9 per cent. The stepwise introduction of these variables improves the adjusted R^2. GDP per capita is also positively and strongly associated with the square term of fixed-broadband penetration at a significance level of 99.9 per cent (Model 5), indicating a greater impact with increasing broadband penetration. The labour force growth rate is only significant at a 10 per cent level. Fixed-telephone network penetration does not appear to be statistically significant and the term has a very small effect on GDP per capita.

Table 4.1: Results for fixed-broadband stepwise linear regression

Variable	Coefficients					
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Constant	7.957***	6.386***	5.193***	5.165***	5.152***	5.156***
FBBpen	0.370***	0.259***	0.244***	0.244***	0.302***	0.244***
School		0.803***	0.851***	0.857***	0.831***	0.863***
FCFpGDP			0.344***	0.349***	0.312**	0.351***
ΔLFP				1.300E-4*	1.433E-4**	1.300E-4*
FLpen						-3.500E-3
FBBpen^2					0.0336***	
Adjusted R^2	0.473	0.565	0.574	0.579	0.595	0.577

*** – significant at the 99.9% level; ** – significant at the 99% level; * – significant at the 95% level.

Instrumental variable regression

Fixed-telephone network penetration was used as an instrument to predict fixed-broadband penetration. The predicted fixed-broadband values are then used in a second-stage regression to assess the impact of fixed broadband on GDP per capita. Fixed-broadband penetration was found to have a statistically significant positive effect on economic growth, with a 10 per cent increase in fixed-broadband penetration resulting in a 2.3 per cent increase in GDP per capita (Table 4.2). The variables for fixed capital formation and average years of schooling also have a statistically significant positive effect on GDP per capita. However, the change in labour force participation, also with a positive effect on GDP per capita, has only a weak significance (at the 10 per cent level). The diagnostics show that the selected instrument is sufficiently strong.

Table 4.2: Fixed-broadband IV model results

Variable	Coefficient	t-statistic	Pr (> | t |) Significance
Constant	5.081	6.759	3.830E-11***
FBBpen	0.234	2.905	0.00383**
FCFpGDP	0.361	3.038	0.00250**
School	0.879	4.738	2.800E-06***
ΔLFP	1.300E-04	1.884	0.06014
Observations	511		
Adjusted R^2	0.578		
Weak instrument test		28.334	1.540E-7***
Wu-Hausman test		0.016	0.9

*** – significant at the 99.9% level; ** – significant at the 99% level; * – significant at the 95% level.

As the instrumental variable approach does not allow the calculation of a critical mass for the effect of broadband penetration, the effect of fixed-broadband penetration levels was explored using dummy variables. Similarly to the approach of Czernich et al. (2011),[57] dummy variables for the introduction of broadband and various fixed-broadband penetration levels were investigated, as follows:

- a dummy for the year fixed broadband was introduced (*FBB.Yo*)
- a dummy for the second year of fixed-broadband introduction (*FBB.Y1*)
- a dummy variable after the fixed-broadband penetration exceeds 10 per cent (*FBB10*)
- a dummy variable after the fixed-broadband penetration exceeds 20 per cent (*FBB20*).

The introduction of fixed broadband in itself does not appear to have any significant impact on GDP per capita, until the penetration level reaches a critical mass. However, the relatively low level of fixed-broadband penetration in almost all the countries within the sample creates difficulties in identifying a threshold effect. The only statistically significant result was for a dummy variable denoting fixed-broadband penetration of at least 20 per cent (Table 4.3). There are only three countries–Singapore, Bahrain and the Bahamas – with a fixed-broadband penetration higher than 20 per cent during the study period (Figure 4.1), representing just 17 observations out of a total of 511 in the dataset. As these countries are not typical LDCs, LLDCs and SIDS, it is possible that the threshold dummy variable may also be capturing other characteristics common to their more developed economies, in addition

[57] Czernich et al., op. cit.

to their higher level of fixed-broadband penetration. Nevertheless, the inclusion of this dummy variable does improve the fit of the model. Figure 4.2 shows the level of fixed-broadband penetration for the countries considered in the analysis as at 2016.

Table 4.3: Fixed-broadband IV model results with a dummy variable for a fixed-broadband threshold of 20 per cent (FBB20)

Variable	Coefficient	t-statistic	Pr (> | *t* |) Significance
Constant	5.506	6.955	1.10E-11***
FBBpen	0.202	2.43	0.0154*
FCFpGDP	0.350	3.094	0.0021**
School	0.870	4.887	1.380E-06***
ΔLFP	1.320E-4	1.938	0.0531
FBB20	1.558	5.982	4.17E-9***
Observations	511		
Adjusted R^2	0.623		
Weak instrument test		26.38	3.98E-7***
Wu-Hausman test		0.002	0.964

*** – significant at the 99.9% level; ** – significant at the 99% level; * – significant at the 95% level.

Figure 4.1: Fixed-broadband penetration in Singapore, the Bahamas and Bahrain

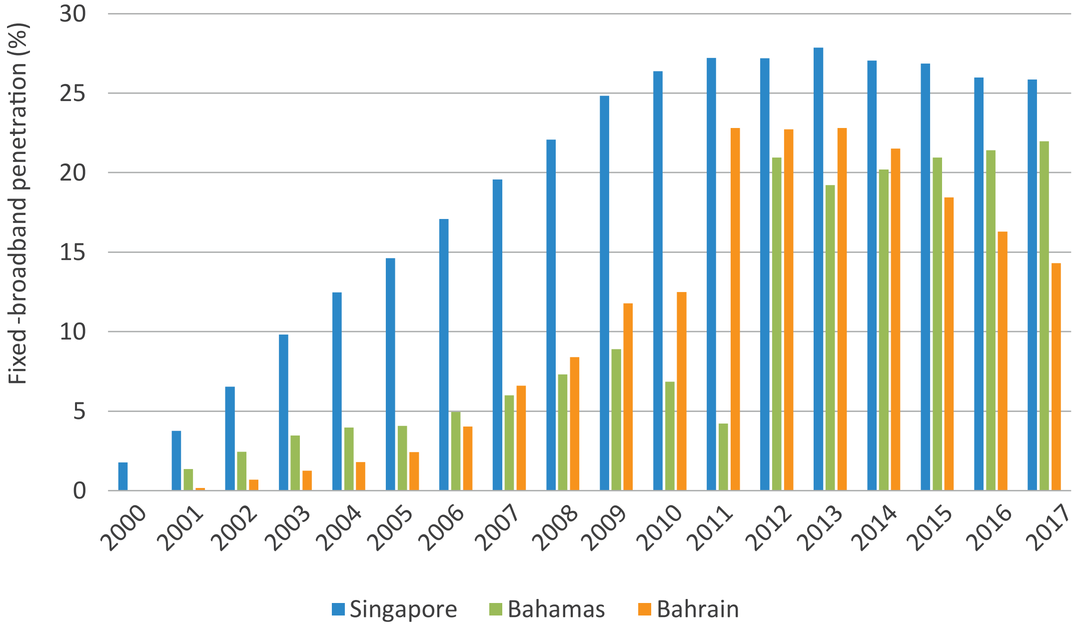
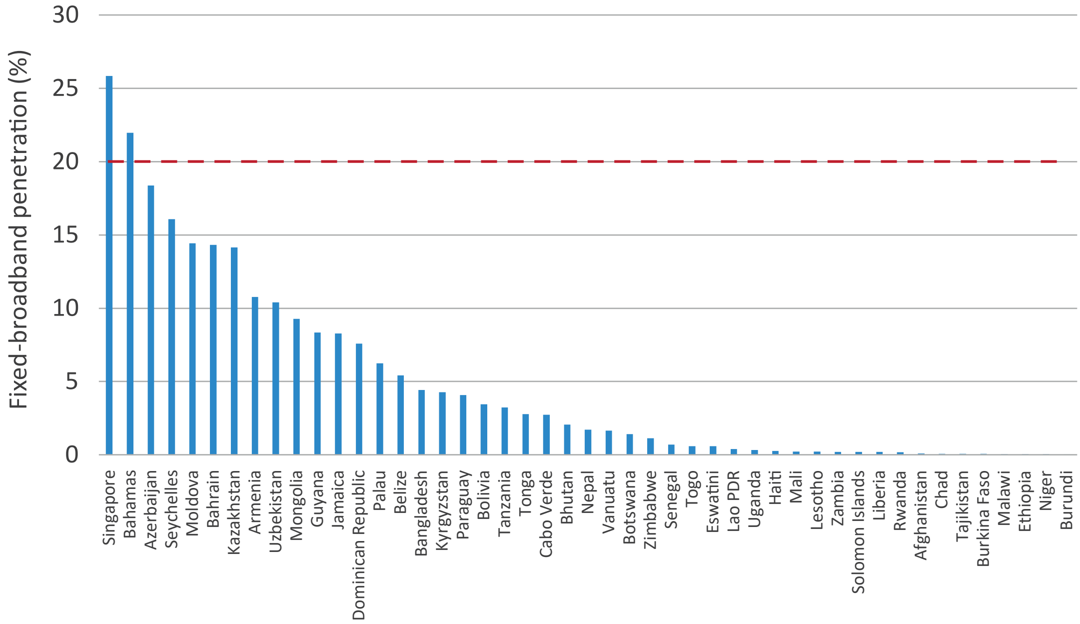


Figure 4.2: Fixed-broadband penetration by country as at 2017, compared to the 20% threshold



4.2 Mobile broadband

For modelling the economic effect of mobile broadband, GDP per capita was selected as the dependent variable, the independent variables being:

- mobile-broadband penetration (*MBBpen*)
- fixed capital formation as a percentage of GDP (*FCFpGDP*)
- average years of schooling (*School*)
- percentage change in labour force participation (*ΔLFP*)
- dummy variable for SIDS (*SIDS*).

For predicting mobile-broadband penetration, one instrumental variable was used: 3G, 4G and WiMAX mobile coverage (*MBBcov*).

The square of mobile-broadband penetration was included to capture a potential nonlinear relationship between GDP per capita and mobile-broadband penetration.

Stepwise linear regression

Table 4.4 shows the results of the stepwise linear regression model for mobile broadband. Mobile-broadband penetration, average years of schooling and fixed capital formation show a strong association with GDP per capita at a significance level of 99.9 per cent. The stepwise introduction of these variables improves the adjusted R^2. As with fixed broadband, GDP per capita was found to be positively and strongly associated with the square term of mobile-broadband penetration at a significance level of 99.9 per cent (Model 5). The quadratic relationship indicates an increasing impact of mobile broadband on GDP per capita with increasing penetration. The labour force growth rate is only significant at a 90% level. Mobile-broadband coverage (per 100 inhabitants) does not appear to be statistically significant and has a very low regression coefficient.

Table 4.4: Results for mobile-broadband stepwise linear regression

Variable	Coefficients					
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Constant	6.657***	4.675***	3.598***	3.549***	3.966***	4.314***
MBBpen	0.375***	0.195***	0.196***	0.198***	-0.063	0.153***
School		1.351***	1.346***	1.350***	1.180***	0.964***
FCFpGDP			0.342**	0.357**	0.300**	0.158***
ΔLFP				1.280E-4	1.591E-4	7.620E-5
MBBcov						0.094
SIDS						1.393***
$MBBpen^2$					0.084***	
Adjusted R^2	0.211	0.474	0.486	0.487	0.579	0.678

*** – significant at the 99.9% level; ** – significant at the 99% level; * – significant at the 95% level.

Instrumental variable regression

3G, 4G and WiMAX network coverage (MBBcov) was used as an instrument to predict mobile-broadband penetration. The predicted mobile-broadband values are used in a second-stage regression to assess the impact of mobile broadband on GDP per capita. Mobile-broadband penetration had a statistically significant positive impact on economic growth, with a 10 per cent increase in mobile-broadband penetration resulting in a 2.8 per cent increase in GDP per capita (Table 4.5). Average years of schooling and the SIDS dummy are both statistically significant, and have a positive effect on GDP per capita. However, fixed capital formation and the change in labour force participation are not statistically significant, although they also have a positive effect on GDP per capita. Noteworthy is that the fixed capital formation is statistically significant before including SIDS as a dummy variable. SIDS considered in the model have a significantly higher GDP per capita, and consequently higher capital formation per capita, than non-SIDS. A possible explanation is that the effect of SIDS was absorbed by the fixed capital formation per capita variable before introducing SIDS as a dummy variable. We note also that removing countries with high GDP per capita, such as Singapore and Bahrain, from the sample improves the statistical significance of fixed capital formation for the model with the SIDS dummy variable.

Table 4.5: Mobile-broadband IV model results

Variable	Coefficient	t-statistic	Pr (> | *t* |) Significance
Constant	4.491	12.746	< 2E-16***
MBBpen	0.280	4.436	1.260E-05***
FCFpGDP	0.168	1.608	0.109
School	0.874	8.018	1.990E-14***
ΔLFP	9.255E-05	0.870	0.385
SIDS	1.377	12.255	<2E-16***
Observations	329		
Adjusted R^2	0.6612		
Weak instrument test		49.956	9.750E-12***
Wu-Hausman test		4.459	0.0355*

*** – significant at the 99.9% level; ** – significant at the 99% level; * – significant at the 95% level.

In addition, four more dummy variables were used to investigate the impact of technology introduction and mobile-broadband threshold effects:

- a dummy for the year mobile broadband was introduced (*MBB.Yo*)
- a dummy for the second year of mobile-broadband introduction (*MBB.Y1*)
- a dummy variable after the mobile-broadband penetration exceeds 10 per cent (*MBB10*)
- a dummy variable after the mobile-broadband penetration exceeds 20 per cent (*MBB20*)
- A dummy variable after the mobile-broadband penetration exceeds 30 per cent (*MBB30*).

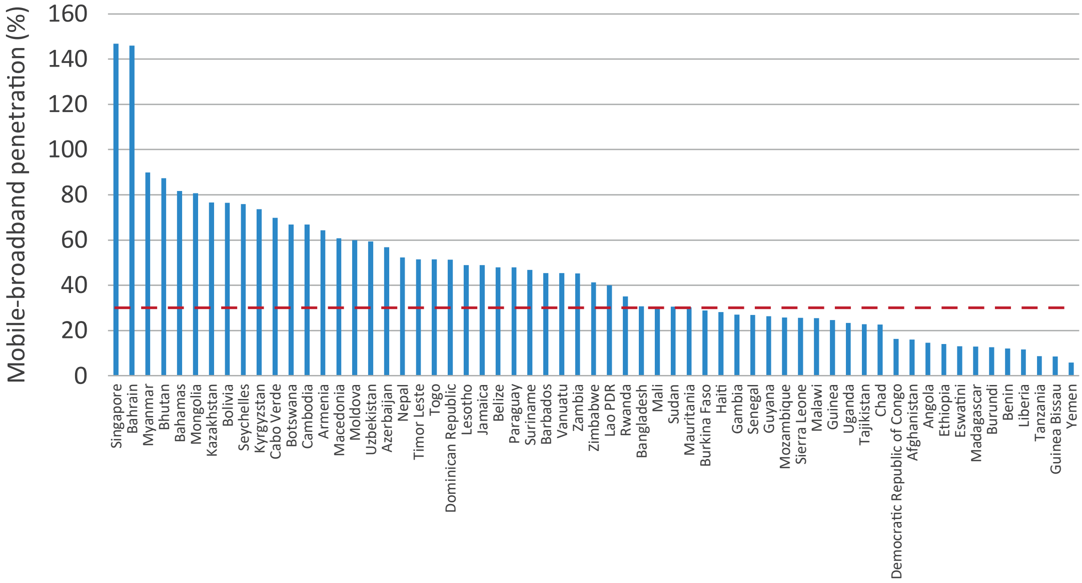
Exploring the effects of the introduction of mobile broadband and market maturity through these dummy variables, it was found that only a dummy variable for a mobile market penetration of 30 per cent was statistically significant (Table 4.6). The results show a strong, and statistically significant, association between GDP per capita and a mobile-broadband penetration above 30 per cent (at the 99.9 per cent level). This suggests that more economic benefits flow from mobile broadband once the 30 per cent threshold has been reached. The introduction of mobile broadband does not appear to have an abrupt impact on GDP per capita.

Table 4.6: Mobile-broadband IV model results with a dummy variable for mobile-broadband threshold (MBB30)

Variable	Coefficient	t-statistic	Pr (> | *t* |) Significance
Constant	3.314	7.378	1.39E-12***
MBBpen	0.249	1.976	0.0490*
FCFpGDP	0.164	1.596	0.112
School	8.614	8.862	<2E-16***
ΔLFP	9.538E-5	0.919	0.359
SIDS	1.376	12.34	<2E-16***
MBB30	0.113	0.412	0.681***
Observations	329		
Adjusted R^2	0.669		
Weak instrument test		12.636	0.00044***
Wu-Hausman test		1.982	0.16015

*** – significant at the 99.9% level; ** – significant at the 99% level; * – significant at the 95% level.

Figure 4.3: Mobile-broadband penetration by country as at 2017



Limitations of the analyses

Owing to the lack of relevant data for many LDCs, LLDCs and SIDS, there is potentially some bias within the sample data. The countries in the sample will be those that have the resources to collect economic and ICT market data. Moreover, in particular, countries actively measuring ICT progress are more likely to have implemented programmes that promote ICT as a means for economic growth.

There are relatively few SIDS within the sample data – only 14 of the 57 SIDS are represented in the sample. Two of the sample countries are Singapore and Bahrain, neither of which could be considered typical of LDCs or SIDS. Omitting Singapore and Bahrain had little effect on the outcome of the analyses. However, this might not be the case if a sufficiently large sample of low-income SIDS were available to estimate SIDS-specific models.

The sample for the fixed-broadband model is dominated by LLDCs – around 60 per cent of the observations are from this group. For many of the sample countries, data were available for only a relatively short time series. In the case of the mobile-broadband model, over half of the 62 sample countries had five or fewer data observations. For the fixed-broadband model, four of the 47 sample countries had five or fewer observations. With such short time series, it may still be premature to assess whether broadband has had any positive effect on economic growth for the countries within the sample.

Zambia – E-learning

It is notable that average length of schooling is a significant variable in the analysis. Higher educational levels have a positive impact on income. However, the widespread availability of learning resources is a key challenge in many LDCs. The Zambia Research and Education Network (ZAMREN) is a specialized ISP which supports 97 research and education communities in Zambia. As an association of tertiary level research and education institutes, it has a collective goal of securing low-cost broadband connectivity for all its members, sharing their educational resources and providing advanced ICT services. The membership of ZAMREN is summarized in Table 4.7.[1]

[1] World Bank (2016), *The role and status of national research and education networks (NRENs) in Africa*, June 2016.

Table 4.7: ZAMREN membership

Type of institution	Number of institutions connected	Range of bandwidth provided (Mbit/s)
Universities	7	7.5 – 230
Teacher-training colleges	2	6 – 9
Colleges of further education	18	3 – 15
Technical high schools	6	1.5 – 7.5
Trades institutes	2	1.5
Research institutes	5	–
International organizations	1	22.5

Source: World Bank

The project's major milestones also include the availability of Eduroam (an international roaming service for users in research, higher education and further education) at the universities. Beyond inter-institutional connectivity, the national research and education network (NREN) also connects to the regional research and education network (RREN) in Eastern and Southern Africa, UbuntuNet.[1]

Regular training is provided for different categories of ZAMREN users. This includes courses for professors with titles such as "Teaching with Technology" and capacity-building workshops for staff who manage the campus network and the network operations centre (NOC), taught in collaboration with the network startup research centre (NSRC).

Zamren was funded by the Dutch government through Nuffic (the Dutch organization for internationalization in education) with assistance from a consortium led by the University of Groningen.

Several universities in Zambia offer online e-learning options. The University of Zambia offers Bachelor-level online degree programmes, which can be either 100 per cent online with no physical class attendance, or blended learning programmes, which include some night or weekend classes. Unicaf University offers online students an e-library and online chat rooms where students can interact. Degree programmes are modular, with sequences beginning each month, and students are able to log in at any time to access or submit coursework. While the University of Lusaka offers online courses, there is still a requirement to attend a two-week residential class immediately before the exams, which are also carried out onsite.[2]

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1 UbuntuNetAlliance, *ZAMREN Zambia*, accessed September 2018 at https://ubuntunet.net/members/nren/zamren/ .

2 The Best of Zambia, *eLearning and distance learning in Zambia*, accessed September 2018, https://thebestofzambia.com/suppliers/education-and-careers/elearning-and-distance-learning .

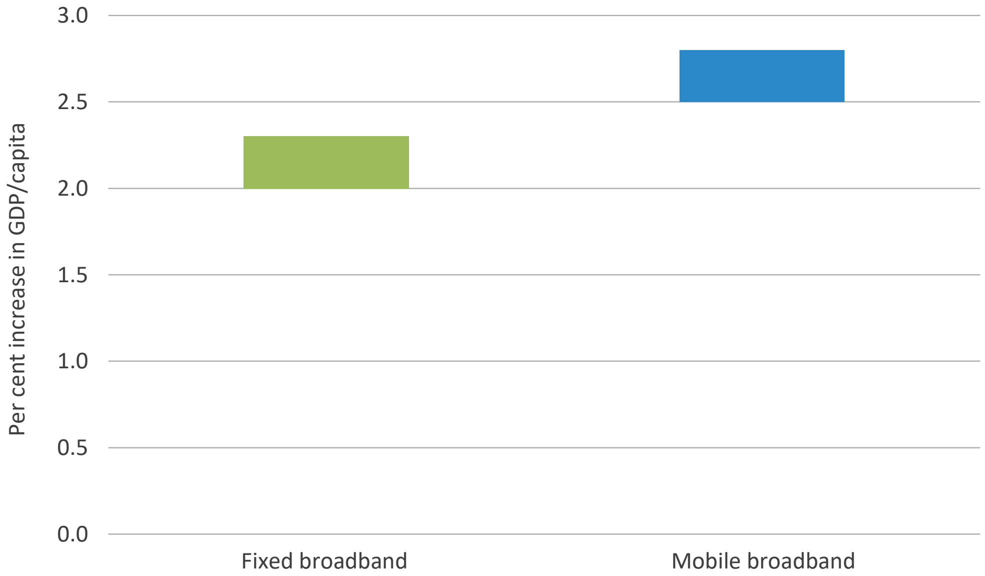
5 Conclusion

The findings of this study confirm that both fixed and mobile broadband have a positive economic impact in the most vulnerable countries. The results indicate that for the time period covered by the study the impact of mobile broadband appears to be slightly stronger than that of fixed broadband (Figure 5.1). Mobile broadband in the sample countries yielded a 2.5 to 2.8 per cent increase in GDP per capita per 10 per cent increase in penetration, compared to 2.0 to 2.3 per cent for fixed broadband. However, the difference is not statistically significant, and consequently it cannot be concluded that mobile broadband delivers a superior outcome to fixed broadband. In addition to direct economic effects of investments, it is possible that the study results also reflect the impact of productivity gains from reduced transaction costs and increased market opportunities.

While the analysis did not identify any immediate economic impact when either technology is first introduced, the impact of broadband appears to get stronger with increased penetration. For both fixed and mobile technologies, the analysis finds that GDP per capita is related to broadband penetration, indicating an increase in the economic impact as broadband penetration increases. Threshold effects were evident for mobile broadband at a level of at least 30 mobile broadband subscriptions per 100 inhabitants. In the case of fixed broadband, low levels of penetration in almost all of the sample countries mean that threshold effects are more difficult to identify. It is important to note that, generally speaking, fixed-broadband coverage, accessibility and penetration is considerably lower in these countries than mobile-broadband availability and uptake. As such, in general, mobile-broadband services are functioning as a substitute for fixed broadband. This is in contrast to the situation in most developed countries, where fixed- and mobile-broadband services tend to be complementary.

From a comparison of the results obtained in this study with those of other studies, it appears that the economic impact of both fixed and mobile broadband is greater in vulnerable countries than in other developing and developed countries. This indicates that a policy of further investment in improving broadband access, connectivity and uptake in LDCs, LLDCs and SIDS could yield higher economic returns than in other countries.

Figure 5.1: Percentage increase in GDP/capita from a 10 per cent increase in penetration for a sample of LLDCs, LDCs and SIDS



Assembling a consistent time-series dataset is a key challenge in economic modelling of developing countries. Missing observations further limit the extent of the analysis. Accordingly, this research could be strengthened and developed with the benefit of a larger and more complete dataset. In particular, it would be possible to model the economic impact of broadband using separate subsamples of LLDCs, LDCs and SIDS. Using econometric techniques, it was possible to discern that GDP per capita is significantly influenced by the characteristics of countries in the SIDS category within the sample. However, there was no evidence of such a relationship for the LLDC and LDC categories.

Nor did the available data for these countries allow examination of the impact of broadband service speeds or quality of service. *A priori,* it is to be expected that the better the service quality and speed, the higher the economic impact. This has also been confirmed empirically in recent studies using a sample of developed countries. Once again, this research could usefully be extended as service quality/speed metrics become available for developing countries.

Annex A: List of LDCs, LLDCs and SIDS

This annex contains three tables with complete lists of the LDCs (Table A.1), LLDCs (Table A.2) and SIDS (Table A.3). Several of the LLDCs and SIDS are also classified as LDCs, and these countries are noted with asterisks in Table A.2 and Table A.3.

Table A.1: Complete list of LDCs

Full list of LDCs	
Afghanistan	Malawi
Angola	Mali
Bangladesh	Mauritania
Benin	Mozambique
Bhutan	Myanmar
Burkina Faso	Nepal
Burundi	Niger
Cambodia	Rwanda
Central African Republic	São Tomé and Príncipe
Chad	Senegal
Comoros	Sierra Leone
Democratic Republic of the Congo	Solomon Islands
Djibouti	Somalia
Eritrea	South Sudan
Ethiopia	Sudan
Gambia	Tanzania
Guinea	Timor-Leste
Guinea-Bissau	Togo
Haiti	Tuvalu
Kiribati	Uganda
Lao PDR	Vanuatu
Lesotho	Yemen
Liberia	Zambia
Madagascar	

Source: UN-OHRLLS

Table A.2: Complete list of LLDCs

Full list of LLDCs	
Afghanistan*	Malawi*
Armenia	Mali*
Azerbaijan	Moldova
Bhutan*	Mongolia
Bolivia	Nepal*
Botswana	Niger*
Burkina Faso*	North Macedonia
Burundi*	Paraguay
Central African Republic*	Rwanda*
Chad*	South Sudan*
Eswatini	Tajikistan
Ethiopia*	Turkmenistan
Kazakhstan	Uganda*
Kyrgyzstan	Uzbekistan
Lao PDR*	Zambia*
Lesotho*	Zimbabwe
* also an LDC	

Source: UN-OHRLLS

Table A.3: Complete list of SIDS

Full list of SIDS	
UN members	Singapore
Antigua and Barbuda	Solomon Islands*
Bahamas	Suriname
Bahrain	Timor-Leste*
Barbados	Tonga
Belize	Trinidad and Tobago
Cabo Verde	Tuvalu*
Comoros*	Vanuatu*
Cuba	**Non-UN members**
Dominica	American Samoa
Dominican Republic	Anguilla
Fiji	Aruba
Grenada	Bermuda
Guyana	British Virgin Islands
Haiti*	Cayman Islands
Kiribati*	Commonwealth of Northern Marianas
Jamaica	Cook Islands
Maldives	Curacao
Marshall Islands	French Polynesia
Micronesia	Guadeloupe
Mauritius	Guam
Nauru	Martinique
Palau	Montserrat
Papua New Guinea	New Caledonia
St. Kitts and Nevis	Niue
St. Lucia	Puerto Rico
St. Vincent and the Grenadines	Sint Maarten
Samoa	Turks and Caicos Islands
São Tomé and Príncipe*	U.S. Virgin Islands
Seychelles	
* also an LDC	

Source: UN-OHRLLS

Annex B: Technical details

B.1 Fixed-broadband IV model

Of the 91 countries in the original sample, just 47 countries remained after the removal of observations with missing data, with a total of 511 observations. Of those countries, 23 were LDCs, 28 LLDCs and 14 SIDS – note that these classifications are not mutually exclusive (Table B.1).

Table B.1: Sample countries included in the analysis of the fixed-broadband model

Country	LDC	LLDC	SIDS
Afghanistan	✓	✓	
Armenia		✓	
Azerbaijan		✓	
Bahamas			✓
Bahrain			✓
Bangladesh	✓		
Belize			✓
Bhutan	✓	✓	
Bolivia		✓	
Botswana		✓	
Burkina Faso	✓	✓	
Burundi	✓	✓	
Cabo Verde			✓
Chad	✓	✓	
Dominican Republic			✓
Eswatini		✓	
Ethiopia	✓	✓	
Guyana			✓
Haiti	✓		✓
Jamaica			✓
Kazakhstan		✓	
Kyrgyzstan		✓	
Lao PDR	✓	✓	
Lesotho	✓	✓	
Liberia	✓		

Country	LDC	LLDC	SIDS
Malawi	✓	✓	
Mali	✓	✓	
Moldova		✓	
Mongolia		✓	
Nepal	✓	✓	
Niger	✓	✓	
Palau			✓
Paraguay		✓	
Rwanda	✓	✓	
Senegal	✓		
Seychelles			✓
Singapore			✓
Solomon Islands	✓		✓
Tajikistan		✓	
Tanzania	✓		
Togo	✓		
Tonga			✓
Uganda	✓	✓	
Uzbekistan		✓	
Vanuatu	✓		✓
Zambia	✓	✓	
Zimbabwe		✓	
Total countries	23	28	14

The resultant model using fixed broadband as an independent variable was:

$$ln(GDPpC_t) = \beta_0 + \beta_1\, ln(FBBpen_t) + \beta_2\, ln(FCFpGDP_t) + \beta_3\, ln(School_t) + \beta_4\, \Delta LFP_t$$

- *ln* – natural logarithm
- β_0 – constant term
- $GDPpC_t$ – GDP per capita at time *t*
- $FBBpen_t$ – fixed-broadband penetration at time *t*
- $FCFpGDP_t$ – fixed capital formation as a percentage of GDP, at time *t*
- $School_t$ – average years of schooling at time *t*
- ΔLFP_t – percentage change in labour force participation from time *t – 1* to time *t*.

Fixed-broadband penetration was estimated via an instrumental variable:

$ln(FBBpen_t) = \alpha_0 + \alpha_1 \, ln(FLpen_t)$

- α_0 – constant term
- $FLpen_t$ – fixed-line penetration at time t.

Model diagnostics (Table B.2) suggest that the instrument is sufficiently strong. The Wu-Hausman test indicates that the IV regression is as consistent as OLS – in other words, that fixed-broadband penetration is endogenous, and thus is determined by the instrumental variable fixed-line penetration.

Table B.2: Diagnostic tests for the fixed-broadband model

	DF 1	DF 2	Statistic	p-value	Significance
Weak instruments	1	506	28.334	1.54E-07	***
Wu-Hausman	1	505	0.016	0.9	
Wald test	4	506	157.2	<2.2E-16	***

*** – significant at the 99.9% level; ** – significant at the 99% level; * – significant at the 95% level.

Dummy variables for LDCs, LLDCs and SIDS were examined. However, inclusion of the latter two dummy variables resulted in fixed-broadband penetration no longer being statistically significant. Adding the LDC dummy yielded a slight improvement in fit.

In comparison with the other countries in the sample, Singapore and Bahrain are relatively wealthy. Removing these two countries from the analysis resulted in fixed-broadband penetration no longer being statistically significant.

B.2 Mobile-broadband IV model

Once missing observations had been removed, there were 62 countries remaining in the sample, of which 37 were LDCs, 29 LLDCs and 14 SIDS – again these categories are not mutually exclusive (Table B.3). Despite a broader scope in terms of countries, there were actually fewer observations than for the fixed-broadband model – 329, as against 511.

Table B.3: Sample countries included in the analysis of the mobile-broadband model

Country	LDC	LLDC	SIDS
Afghanistan	✓	✓	
Angola	✓		
Armenia		✓	
Azerbaijan		✓	
Bahamas			✓
Bahrain			✓
Bangladesh	✓		
Barbados			✓

Country	LDC	LLDC	SIDS
Belize			✓
Benin	✓		
Bhutan	✓	✓	
Bolivia		✓	
Botswana		✓	
Burkina Faso	✓	✓	
Burundi	✓	✓	
Cabo Verde			✓
Cambodia	✓		
Chad	✓	✓	
Democratic Republic of the Congo	✓		
Dominican Republic			✓
Eswatini		✓	
Ethiopia	✓	✓	
Gambia	✓		
Guinea	✓		
Guinea Bissau	✓		
Guyana			✓
Haiti	✓		✓
Jamaica			✓
Kazakhstan		✓	
Kyrgyzstan		✓	
Lao PDR	✓	✓	
Lesotho	✓	✓	
Liberia	✓		
Madagascar	✓		
Malawi	✓	✓	
Mali	✓	✓	
Mauritania	✓		
Moldova		✓	

Country	LDC	LLDC	SIDS
Mongolia		✓	
Mozambique	✓		
Myanmar	✓		
Nepal	✓	✓	
Niger	✓	✓	
North Macedonia		✓	
Paraguay		✓	
Rwanda	✓	✓	
Senegal	✓		
Seychelles			✓
Sierra Leone	✓		
Singapore			✓
Sudan	✓		
Suriname			✓
Tajikistan		✓	
Tanzania	✓		
Timor-Leste	✓		✓
Togo	✓		
Uganda	✓	✓	
Uzbekistan		✓	
Vanuatu	✓		✓
Yemen	✓		
Zambia	✓	✓	
Zimbabwe		✓	
Total countries	37	29	14

The model form is similar to that of the fixed-broadband model, but with the addition of a dummy variable for SIDS countries:

$$ln(GDPpC_t) = \beta_0 + \beta_1\, ln(MBBpen_t) + \beta_2\, ln(FCFpGDP_t) + \beta_3\, ln(School_t) + \beta_4\, \Delta LFP_t + \beta_5\, SIDS$$

- *ln* – natural logarithm
- β_0 – constant term
- $GDPpC_t$ – GDP per capita at time *t*
- $MBBpen_t$ – mobile-broadband penetration at time *t*

- $FCFpGDP_t$ – fixed capital formation as a percentage of GDP, at time *t*
- $School_t$ – average years of schooling at time *t*
- ΔLFP_t – percentage change in labour force participation from time *t* – 1 to time *t*.
- *SIDS* – dummy variable for SIDS (1 if country is a SIDS).

Mobile-broadband penetration was estimated via an instrumental variable:

$$ln(MBBpen_t) = \alpha_0 + \alpha_1 \, ln(MBBCov_t)$$

- α_0 – constant term
- $MBBCov_t$ – highest of 3G, 4G or WiMAX coverage expressed in terms of percentage of the population.

The model diagnostics indicate that the instrument is sufficiently strong (Table B.4). Mobile-broadband penetration, as shown by the Wu-Hausman test, is exogenous – i.e. it is not fully determined by the instrumental variable for mobile coverage.

Table B.4: Diagnostic tests for the mobile-broadband model

	DF 1	DF 2	Statistic	p-value	Significance
Weak instruments	1	323	49.956	9.75E-12	***
Wu-Hausman	1	322	4.459	0.0355	*
Wald test	5	323	129.8	< 2.2E-16	***

*** – significant at the 99.9% level; ** – significant at the 99% level; * – significant at the 95% level.

Dummy variables for LDCs and LLDCs were investigated, but the SIDS dummy proved far superior in improving fit. Excluding Singapore and Bahrain from the sample data did not improve the model's fit.

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Glossary of terms and abbreviations

ΔLFP: Percentage change in labour force participation

2SLS: Two-stage least squares

3SLS: Three-stage least squares

DF: Degrees of freedom

DSL: Digital subscriber line

Elasticity: A measurement of the effect of a (small) change in one variable upon another variable

EU: European Union

FBB.Yo: Dummy variable for the year fixed broadband was introduced

FBB.Y1: Dummy variable for the second year of fixed-broadband introduction

FBB10: Dummy variable after fixed-broadband penetration exceeds 10%

FBB20: Dummy variable after fixed-broadband penetration exceeds 20%

FBBpen: Fixed-broadband penetration

FCC: Federal Communications Commission

FCFpGDP: Fixed capital formation as a percentage of GDP

FDI: Foreign direct investment

FE: Fixed effects

FLpen: Fixed-telephone network penetration

G20: Group of 20 – comprises Argentina, Australia, Brazil, Canada, China, the European Union, France, Germany, India, Indonesia, Italy, Japan, Mexico, the Russian Federation, Saudi Arabia, South Africa, the Republic of Korea, Turkey, the United Kingdom and the United States.

G2B: Government-to-business

G2C: Government-to-consumer

GDP: Gross domestic product

GPT: General purpose technology

ICT: Information and communication technology

ILO: International Labour Organization

ISP: Internet service provider

ITU: International Telecommunication Union

IV: Instrumental variables

LDC: Least developed country

LLDC: Landlocked developing country

MBB.Yo: Dummy variable for the year mobile broadband was introduced

MBB.Y1: Dummy variable for the second year of mobile-broadband introduction

MBB10: Dummy variable after mobile-broadband penetration exceeds 10%

MBB20: Dummy variable after mobile-broadband penetration exceeds 20%

MBB30: Dummy variable after mobile-broadband penetration exceeds 30%

MBBcov: Mobile-broadband coverage

MBBpen: Mobile-broadband penetration

NOC: Network operations centre

NREN: National research and education network

NSRC: National startup research centre

OECD: Organisation for Economic Co-operation and Development

OLS: Ordinary least squares

POLS: Pooled ordinary least squares

PPP: Purchasing power parity

R^2: Coefficient of determination – the proportion of the variance in the dependent variable that is predictable from the independent variables

RE: Random effects

RREN: Regional research and education network

School: Average years of schooling

SEM: Simultaneous equations model

SIDS: Small island developing state

Teledensity: The number of both fixed and mobile subscribers per 100 inhabitants

UN: United Nations

UN-OHRLLS: United Nations Office of the High Representative for the Least Developed Countries, Landlocked Developing Countries and Small Island Developing States

VoIP: Voice over Internet Protocol

VSAT: Very small aperture terminal

ZAMREN: Zambia research and education network

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