ΠΑΝΕΠΙΣΤΗΜΙΟ ΠΕΙΡΑΙΩΣ

UNIVERSITY OF PIRAEUS

On the determinants of the impact of broadband speed on economic growth

ΧΑΣΑΠΟΓΙΑΝΝΗ ΝΑΥΣΙΚΑ

ΕΠ. ΚΑΘΗΓΗΤΗΣ: ΤΣΕΛΕΚΟΥΝΗΣ ΜΑΡΚΟΣ

ΠΕΙΡΑΙΑΣ 2020

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Οι καθοριστικοί παράγοντες της επίδρασης της ταχύτητας των ευρυζωνικών δικτύων στην οικονομική ανάπτυξη

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Abstract

This dissertation aims to measure the impact of broadband speed on economic growth in 20 OECD countries. The macroeconomic indicators for this study were collected from World Bank and ITU databases, except for the speed data, which were gathered from Akamai, a company that provides broadband testing and web-based network diagnostic applications data. With this, annual balanced panel data for 20 OECD countries during the period 2012-2017 were examined. The study found that the estimated coefficient of broadband speed is statistically significant. It is further shown that, for the time period under consideration, the returns from increasing speeds on GDP are positive but diminishing. The upper threshold of speed related gains is moving higher as a result of the “readiness” of the economy (individuals or firms) to make productive use of improved infrastructures through the availability of services that demand more bandwidth.

Acknowledgements

Thank you to my supervisor, Tselekounis Markos, for providing guidance and feedback throughout this project. I am also thankful to the Department of Economics and all its member's staff for all the considerate guidance. To conclude, I cannot forget to thank my family and friends for all the unconditional support.

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1. Introduction

1.1 Next-generation broadband networks

Among the technological advances of the last 50 years, the expansion and technological improvements of telecommunications infrastructure have been some of the most crucial. While the deployment of wireline telecommunications networks allowed large parts of the world's population, especially in developed countries, to communicate via fixed-line telephony, the introduction of first and second-generation wireless telecommunications networks since the 1980's set another landmark for personal communications. However, the progress in information and communications technologies (ICT) was not limited to voice telephony only. Broadband internet technologies such as Digital Subscriber Line (DSL) or Cable Internet have created unprecedented opportunities for worldwide data transmission. In the last years, the deployment of so-called next-generation broadband networks has facilitated much faster up- and download speeds as fiber-based wireline broadband access technologies like FTTH (Fiber-to-the-Home), Fiber-to-the-Building (FTTB) or hybrid Fiber-to-the-Cabinet (FTTC) and Fiber-to-the-Node (FTTN) technologies have started to replace the slower entirely copper- or coax-based first-generation wireline technologies. The introduction of the fourth generation (4G) mobile broadband technology Long Term Evolution (LTE) in 2010 brought substantial speed improvement for the wireless telecommunications networks.

Besides the benefits that these technologies have on the social lives of their consumers, their possible economic benefits have been increasingly emphasized by economic research. Early estimations suggest that broadband technologies can create substantial amounts of consumer surplus. Furthermore, broadband internet is expected to generate new employment opportunities particularly in remote areas as it enables many workers to work from home (so-called telecommuting) and thus reduces the importance of distances.

Due to the development of new innovations and technologies, broadband services currently require more transmission capacity to work properly and efficiently with new content. Higher quality video content and more complex applications on internet services also require faster broadband speed. Hence, policymakers have implemented broadband policy to ensure that countries will have high speed broadband infrastructure for both wired and wireless services.

In 2010, the Federal Communications Commission (FCC) released the National Broadband Plan whose aims include that 'every American should have affordable access to robust broadband service' and 'at least 100 million U.S. homes should have affordable access to actual download speeds of at least 100 megabits per second and actual upload speeds of at least 50 megabits per second' until 2020 (FCC 2010a, pp. 9-10). Similarly, the European Commission launched the Digital Agenda for Europe (DAE) that 'seeks to ensure that, by 2020, (i) all Europeans will have access to much higher internet speeds of above 30 Mbit/s and (ii) 50% or more of European households will subscribe to internet connections above 100 Mbit/s' (European Commission 2010, pp. 19). While achieving these goals promises considerable economic returns, they also go along with substantial costs, in particular for the construction of the necessary new communications infrastructure which is partly or entirely fiber based. It is hence a necessity to carefully evaluate whether these returns will exceed the accompanying costs or whether the expansion of new (high-speed) broadband networks will go along with economic losses.

Even though the importance of broadband speed has been recognized almost everywhere, there are only a few studies investigating this issue in the academic field, especially in empirical research.

In the past, several studies have analyzed the impacts of broadband penetration on economic growth and indicated that higher broadband penetration leads to greater economic impacts. Nevertheless, other characteristics of broadband services such as different speeds of transmission, type of connection, quality of service and service providers are becoming more important to determine the economic impacts, as they vary across countries. Hence, broadband penetration on its own may not be a good measurement of the impacts of broadband services on the economy.

A paper investigating impact of broadband speed on economic growth is the following: Is faster better? Quantifying the relationship between broadband speed and economic growth by George S. Ford.[1] In this paper, the aim is to quantify the relationship between higher broadband speeds (10 Mbps versus 25 Mbps) and the growth rates in important economic outcomes in U.S. counties including jobs, personal income, and labor earnings.

The current study therefore aims to add knowledge from a speed transmission perspective and enrich the empirical evidence in broadband speed studies, which has so far been limited.

1.2 Benefit of greater broadband speed

In 1964, the first commercial modem for computers operated at an internet speed of 300 bps, increasing to 2.4 kbps in 1989 and 28.8 kbps in 1995. In the late 1990s, the Internet speed usually used in the household rose to 56 kbps and, finally, to 1.5 Mbps around the mid-2000s (Atkinson et al., 2009)[2]. The use of video websites such as YouTube, Netflix and other streaming video online websites has greatly increased in the past few years. The greater the quality of the video, the higher the broadband speed that is needed, not only for entertainment purposes but it is also increasingly believed that video communication will provide several benefits in the future. For example, the use of voice over Internet protocol (VOIP), video conferencing, online education and telehealth all need higher speed capacity to work efficiently. Atkinson et al. (2009)[2] further explained that faster broadband services from next generation broadband can significantly improve four main functionalities of internet services compared with traditional broadband: 1) significantly faster file transfers, both sending and receiving, 2) enabling video streaming applications, 3) high quality real-time communication and 4) enabling users to use many applications at the same time.

With these benefits from new applications and content, higher broadband speed has been emphasized through several reports by both the public and private sectors as contributing more benefits than lower speed broadband. Some scholars also suggest that higher broadband speeds create more employment and stimulate better economic growth (see Katz et al., 2010[3], and Rohman and Bohlin, 2012)[4]. This is not only limited to the ICT sector, high speed broadband also contributes to the improvement of other sectors and businesses, from medication and education to entertainment. ITU (2012)[5] has concluded that broadband development may benefit an economy into four categories: 1) direct job and act creation through the broadband development project, which works in the same way as in any infrastructure project, 2) the externalities at both business and household level lead to productivity gains in firms and higher household incomes in residential adoption, which ultimately contributes to economic growth, 3) the benefits in the form of consumer surplus when consumers pay for the service below the level of their willingness to pay and 4) benefits through other sectors such as access to the public, entertainment, education, health care and banking services. Similarly, a higher speed of transmission of broadband services is likely to stimulate greater and more efficient effects in addition to these four possibilities. These effects are clearer in the second and fourth categories. For instance, with the use of video content from ultra-fast broadband, the development of education and health information can become faster and more efficient while the business sector can lower its travel costs with video conferencing. Higher broadband speeds can have indirect effects on contents and applications. It is therefore likely that there will be more development of new content and supports the idea of greater benefits of high-speed broadband compared with normal broadband in three areas: 1) increased economic growth (GDP), 2) job creation and 3) public welfare improvements (measured by the Human Development Index, HDI). To illustrate the benefits of broadband speed and economic output, the relationship between one of economic outputs (GDP per capita) and average broadband speed in OECD countries is presented in Figure 1. Figure 1 shows that in the OECD countries, those with a higher average broadband speed generally have higher GDP per capita than those with a lower average broadband speed.

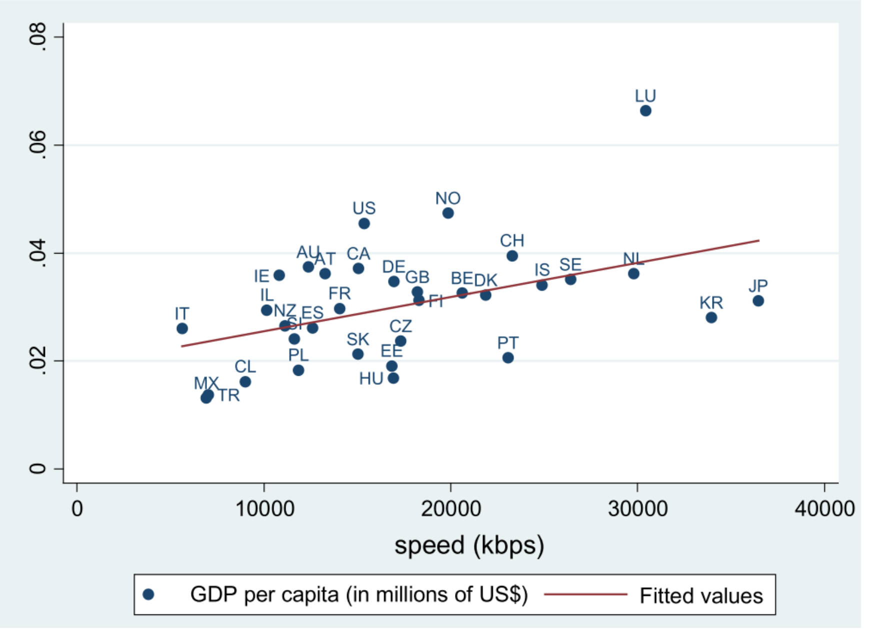

Figure 1: GDP per capita – Broadband speed

Source: Impact of broadband speed on economic outputs: An empirical study of OECD countries Kongaut, Chatchai; Bohlin, Erik Conference Paper

1.3 The concept of Broadband Speed

Broadband internet access, often referred to as “broadband,” is defined as a high data transmission, which is always connected to the internet, typically contrasted with temporary, lower-rate, dial-up access. The internet consists of shared resources, to which anyone can have access using a link – a data communications system – that is connected to shared resources. The data communications system transports information formatted as binary digits called “bits.”

These bits are grouped into delimited information packets that are transported via communications links. Where there is no information transfer, no information packets are being shipped over the link. In other words, the link lays idle. Most communication systems take advantage of the fact that not all users use the links at the same time. Links are shared between many users. A user occupies transfer capacity when that user sends or receives information.

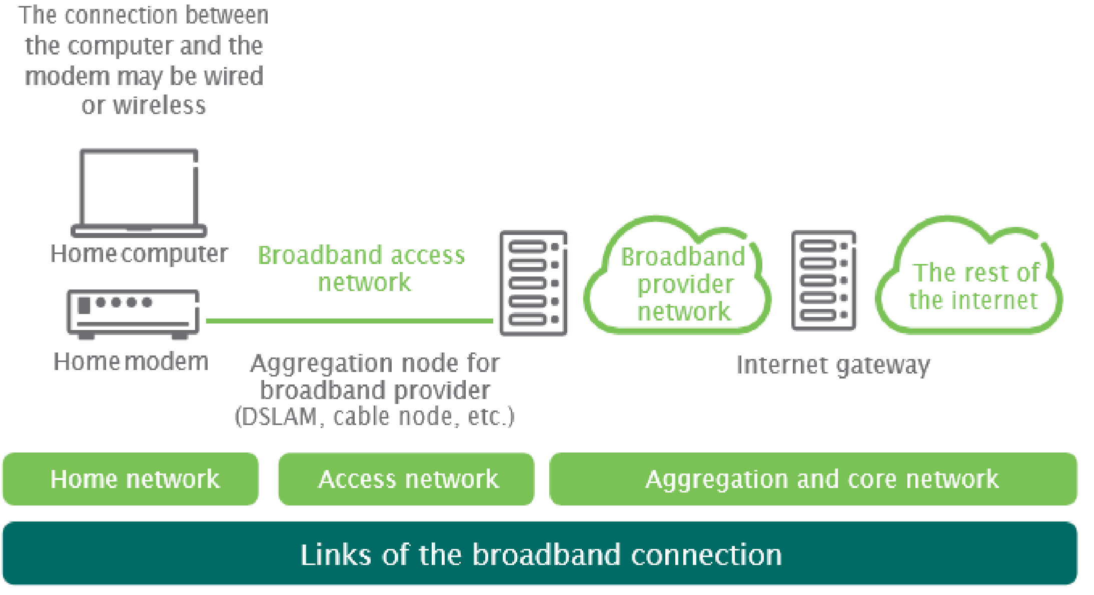

Figure 2: Schematic of a typical broadband connection

Source: Ericsson, Bauer, Clark and Lehr, 2010

1.4 Defining speed

The transmission rate of a data communications system is commonly referred to as its “speed.” Clarity regarding the meaning of this is of great importance, as many different definitions exist. The transmission rate depends on the characteristics of the dedicated links and how the shared resources are allocated and loaded. Broadband speed depends on:

> The physical characteristics of the connection links, for example distance and bandwidth

> Policies set for allocation of shared resources, for example priorities and queuing

> The behavior of other users loading the shared resources

Hence, the achieved broadband speed is not equal to the bandwidth, as many parameters play a role here. Traditionally, dial-up connections were used to access the internet. These are still being used in many emerging economies. A dial-up connection uses the telephone network to link the computer to the internet, and has a limited but predictable access capacity, normally restricted to 56 Kbps.

A broadband connection is – in contrast to dial-up – capable of always being on. Traditionally, internet access speeds of 256 Kbps and above have been considered broadband (OECD), but recent definitions of basic/ functional broadband set the lower limit at 2–4 Mbps (EU, FCC). The exact speed threshold that defines broadband is not highly important to this study, instead it is the comparison between different internet access speeds that serves a purpose here.

The link with least amount of unused bandwidth along the path determines the end-to-end available bandwidth — the “speed” connection. The link with the least amount of unused bandwidth along the path determines the end-to-end available bandwidth, see Figure 3.

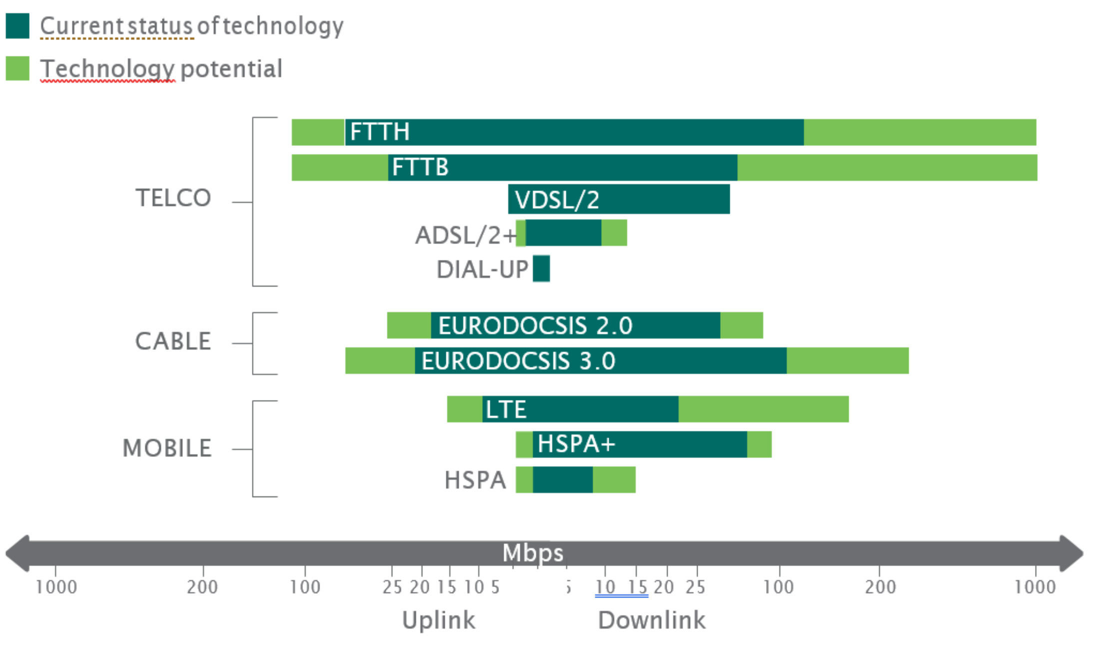

Figure 3: Typical net bit rate by technology

Source: Arthur D. Little analysis

Here the difference between capacity and the maximum possible speed becomes clear. The capacity is the total bandwidth of a link, whereas the maximum possible speed for a user is the amount of available bandwidth not currently used. Both capacity and available bandwidth are measured in bits per second.

A link's capacity is affected by the technology used. Most technologies today normally do not exceed 100 Megabits per second per connection, but there is potential to reach 1 Gigabit per second, particularly with optical fiber technology.

1.5 Measuring speed

When discussing broadband speed, it is important to define which bits are actually included. There are several ways of counting bits. Either gross bits or net bits are considered. Gross bits are the total number of physically transferred bits, including user data as well as control signals. Net bits exclude basic control bits, but include some control signaling (the protocol) and user data. Net bits form a net data packet, which consists of three main parts:

- A header which contains the sender's and the recipient's IP addresses, the protocol governing the information, etc.
- The original information – the body
- A trailer which informs the receiver that the data packet is complete

Lastly, data transfer rate can be referred to, which is the achieved average net bit rate that is delivered to the applications, excluding all protocol overhead and potential retransmissions. This is the actual useful data rate. For instance, when downloading a file from the internet, the data transfer rate is the file size (measured in bits) divided by the file transfer time. In addition to these measured speeds, one may consider the advertised speed communicated by the operators. Ideally, when analyzing the effects of broadband speed, achieved speed is preferable over advertised speed, since the latter irregularly corresponds to the real speed experienced by the user (Figure 4).

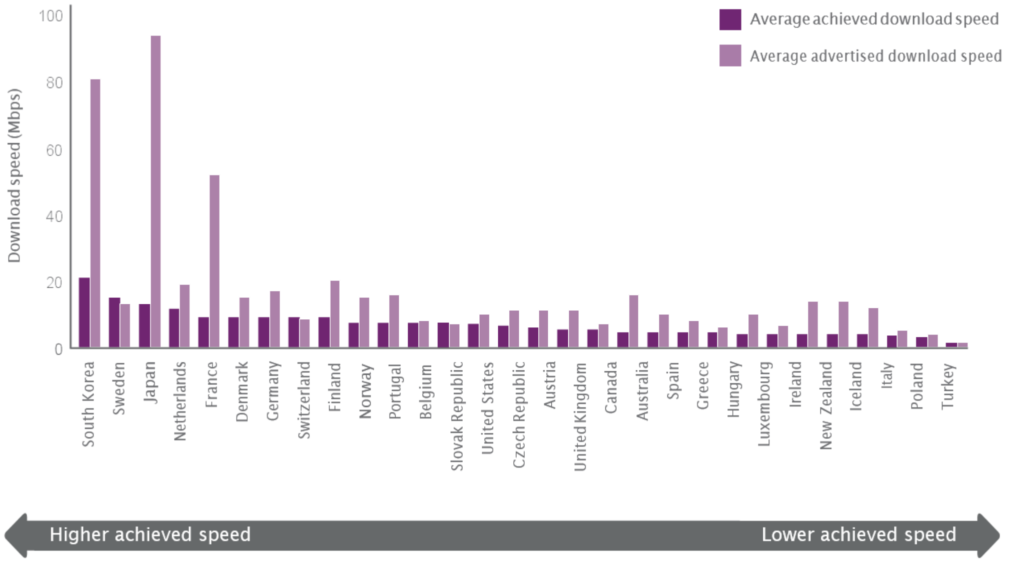

Figure 4: Comparing advertised speed and achieved speed in OECD countries (2009)

Source: OECD, Ookla speedtest.net

While advertised speed is readily available and gives an indication of the theoretical maximum, which may play a role in technology investment decisions, it offers poor insights into the actual user experience and risks biasing the data. Achieved speed on the other hand, is based on actual data from speed testing institutes (such as Ookla).

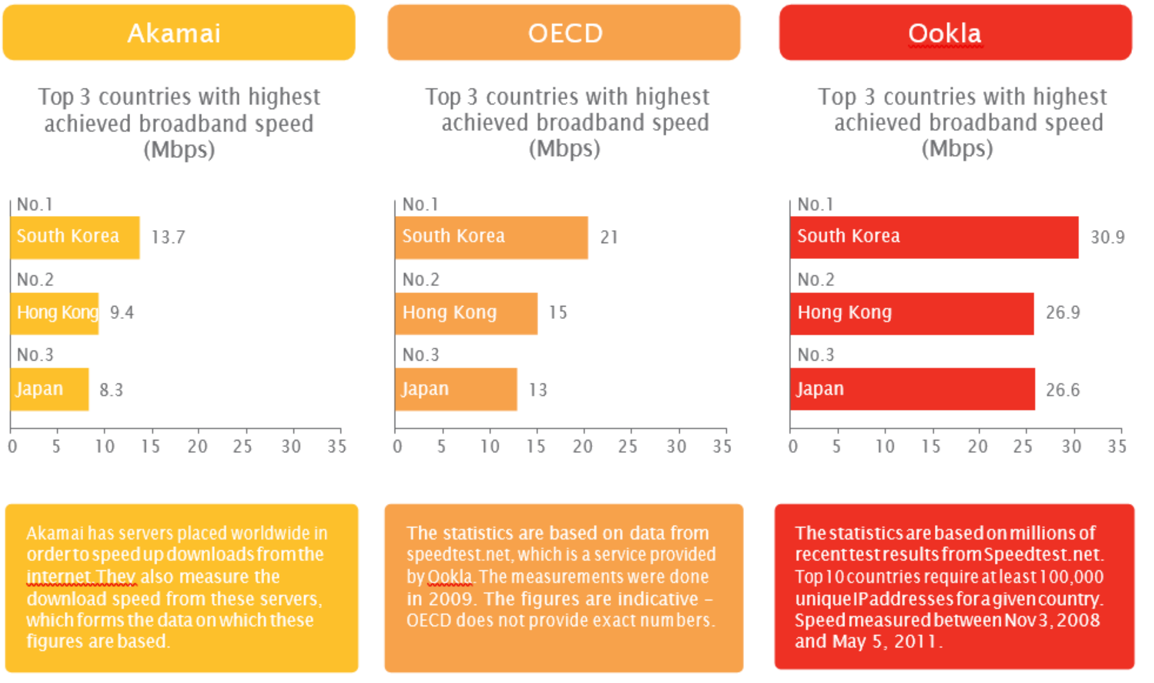

Figure 5: Measurements of achieved speed from three different sources

Source: Akamai (2010), Benkler (2009), Ookla's netindex.con, accessed on May 6, 2011

As seen in Figure 5, three different, well respected organizations have estimated different results in terms of top three achieved broadband speed rates (Mbps). Results are comparable in the ranking between the countries yet differ considerably between institutes for measuring the same country. This illustrates the immaturity of broadband speed measurement techniques and concepts.

Peak speed is also based on real data but is likely to be closer to advertised speed since it counts the highest achieved speed. This is heavily dependent on the user's internet behavior and is not representative of the speed they experience over time. Finally, capacity consumption rate considers not only the flow rate but the actual volume of the flow. While this measurement adds an additional dimension, it does not reflect the speed but rather the consumption per time unit.

Keeping these considerations in mind, average achieved speed was the chosen measurement. This is due to its relatively high accuracy in capturing the concept of speed and its acceptable level of data availability compared to, for example, peak speed measures.

2. Literature Review on the economic impacts of broadband internet

With huge amounts of capital being dedicated to the technology, it is natural that policy makers and researchers in the social sciences have begun to analyze the economic and social impact of broadband. In fact, social scientists and policy makers had been researching the economic contribution of information and communication technologies for quite a while. The first analyses of the impact of fixed telephone density on economic growth were conducted in the mid-1970s by World Bank researchers. Ever since, enhancements both in the quality of data and sophistication of econometric tools have yielded continuous improvement in tackling the question of economic impact of telecommunications. Broadband, however, represents a new challenge for researchers. First, its deployment has proceeded at an incredibly fast pace. Within 12 years, broadband has been adopted by over 62 per cent of households in the United States, 80 per cent in the Netherlands and 95.9 per cent in Korea (ITU, 2010; OECD, 2010).

Consequently, the length of time series data of broadband adoption is considerably shorter than for voice telecommunications. Second, only the countries that have understood early on its economic potential have proceeded to collect statistics at the beginning of the diffusion process. Third, since broadband is an access technology for data communications, it only has an economic effect in combination with the adoption of information technology, and the implementation of organizational and process changes in enterprises.

In sum, because broadband has been deployed in such a short time span and it is an enabler of remote information technology access, it has represented a substantial research challenge. The primary challenge, though, remains the lack of disaggregated datasets that allow to quantitatively establish the conditions under which broadband has an economic effect. These methodological challenges rendered the broadband policy making process quite complex. It is difficult to ascertain precisely if broadband contributes to economic growth or it is deployed because of growing development. This problem risks repeating the debate started when economists started looking at the impact of computing. As expected, the original results were not conclusive. Robert Solow, the Nobel Economics laureate from MIT, concluded at the time “you can see the computer age everywhere but in the production statistics”. His conclusion kicked off a skeptical body of research and theory. Paul Krugman, another Nobel laurate, stated in the early 1990s that “either the technology isn’t all it's cracked up to be, or we haven’t yet seen the impact of the new technology on the economy”, while Robert Gordon concluded that computers made only a small contribution to productivity because “there is something wrong with computers”.

Luckily enough, the availability of larger data sets at the beginning of the 21st century allowed researchers to more precisely estimate the effects of computing. This led to the development of a new theory based on growth accounting economics that could not only pinpoint the economic impact of information technology, but also identify differential effects by region of the world.

For example, a study relating labor productivity growth on ICT investments on an industry level concluded that the faster productivity growth in the US compared to EU countries can be attributed to a larger employment share in the ICT producing sectors and a faster growth in industries that intensively use ICT. No one doubts today that computing and ICT in general have significantly contributed to economic growth in the industrialized world during the 1990s and 2000s.

The evidence on broadband is not quite conclusive, however. As detailed above, the study of the economic effects of broadband presents several methodological challenges. Research has confronted these challenges by proceeding along three avenues.

In the first place, macro-economic research grounded on the Harvard economist Robert Barro's endogenous technical change model has analyzed the aggregate impact of broadband on economic development. In this case the guiding question is what is the contribution of broadband to GDP growth, productivity and employment? The second avenue has researched the impact of broadband from the microeconomic perspective. It is conducted at the firm level and emphasizes the contribution of broadband to business process efficiency and sales growth. The key issue here is to understand the return on broadband and IT investment at the firm and sector level. The third school of thought tackles this last question from a qualitative perspective, choosing the case study as its primary analytical tool.

Nevertheless, the evidence accrued by these three bodies of research is beginning to support the hypothesis that broadband has an important economic impact. However, when comparing findings across research, several caveats need to be raised.

First, broadband exhibits a higher contribution to economic growth in countries that have a higher adoption of the technology (this could be labelled the “critical mass” or “return to scale” theory”). Second, broadband has a stronger productivity impact in sectors with high transaction costs, such as financial services, or high labor intensity, such as tourism and lodging. Third, in less developed regions, as postulated in economic theory, broadband enables the adoption of more efficient business processes and leads to capital-labor substitution and, therefore loss of jobs (this could be labelled the “productivity shock theory”). Fourth, the impact of broadband on small and medium enterprises takes longer to materialize due to the need to restructure the firms' processes and labor organization in order to gain from adopting the technology (this is called “accumulation of intangible capital”).

Finally, the economic impact of broadband is higher when promotion of the technology is combined with stimulus of innovative businesses that are tied to new applications. In other words, the impact of broadband is neither automatic nor homogeneous across the economic system.

This emphasizes the importance of implementing public policies not only in the areas of telecommunications regulation, but also in education, economic development and planning, science and technology, and others.

The first effect results from the construction of broadband networks. In a way similar to any infrastructure project, the deployment of broadband networks creates jobs and acts over the economy by means of multipliers. The second effect results from the "spill-over" externalities, which impact both enterprises and consumers. The adoption of broadband within firms leads to a multifactor productivity gain, which in turn contributes to growth of GDP. On the other hand, residential adoption drives an increase in household real income as a function of a multiplier. Beyond these direct benefits, which contribute to GDP growth, residential users receive a benefit in terms of consumer surplus, defined as the difference between what they would be willing to pay for broadband service and its price. This last parameter, while not being captured in the GDP statistics, can be significant, insofar that it represents benefits in terms of enhanced access to information, entertainment and public services.

Research aimed at generating hard evidence regarding the economic impact of broadband is fairly recent. The results of the research and the evidence generated so far fall into six areas:

1. Contribution to economic growth ("positive externalities").

2. Contribution to productivity gains.

3. Contribution to employment and output of broadband deployment ("countercyclical effect").

4. Creation of consumer surplus.

5. Improvement of firm efficiencies.

6. Regional development

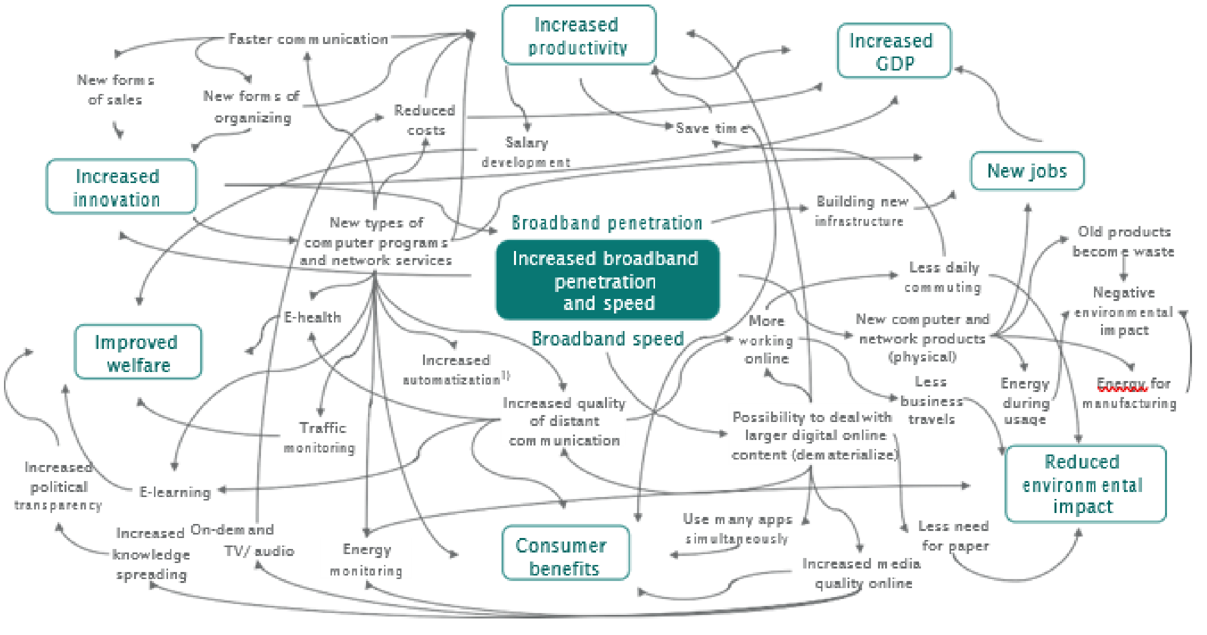

Figure 6: Schematic of effects stemming from increased broadband penetration and speed

Source: Socioeconomic effects of broadband speed Research by Ericsson, Arthur D. Little and Chalmers University of Tech

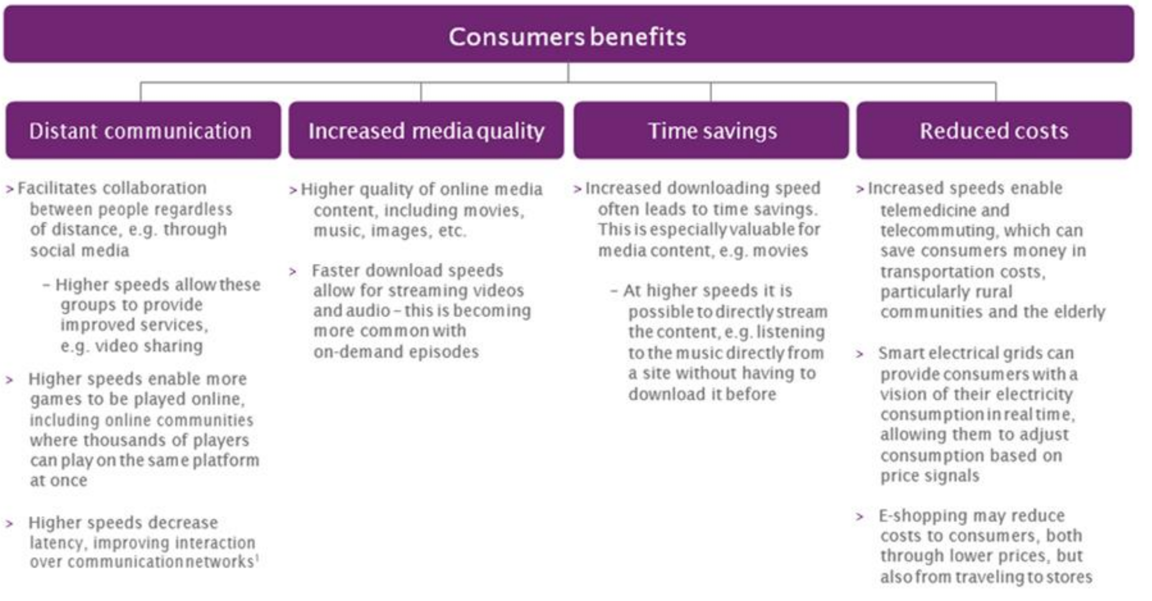

Figure 7: Broadband speed benefits directly related to the consumer

Source: Crandall et al. (2010), Erick et al. (2009), Arthur D. Little analysis

2.1 Contribution to economic growth

2.1.1 Mass Threshold and Saturation effect

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

Research aimed at generating hard evidence regarding the economic impact of broadband is fairly recent. The review of the research indicates that there are multiple approaches to estimate the economic impact of broadband, ranging from highly sophisticated econometric techniques to qualitative micro-level case studies. Not all approaches are suitable to all situations. The choice of analytical techniques will be driven by the availability of data and type of effect to be analyzed.

The study of the impact of broadband on economic growth covers numerous aspects, ranging from its aggregate impact on GDP growth, to the differential impact of broadband by industrial sector, the increase of exports, and changes in intermediate demand and import substitution. While the research on the contribution of broadband to GDP growth has confirmed its positive impact, it has also yielded results that vary widely.

Many of the problems identified stem from data availability, since researchers lack a host of useful variables and must work at high levels of aggregation. However, despite the degree of discrepancies, the research consistently concludes that broadband has a significant positive effect on GDP growth. In addition to measuring the aggregate economic impact at the macro level, research on the economic impact of broadband has focused on the specific processes that underlie this effect. So far two questions have been studied in detail:

1. Does the economic impact of broadband increase with penetration and can we pinpoint a saturation threshold when decreasing returns to penetration exist?

2. What explains the lagged effect of broadband on the economy?

A critical element of the evolving theoretical framework of network externalities of broadband is the impact infrastructure penetration levels may have on output. Is there a linear relationship between broadband adoption and economic growth? Or are we in the presence of a more complex causality effect? The "critical mass" findings of research of the impact of telecommunications on the economy, indicates that the impact of broadband on economic growth may only become significant once the adoption of the platform achieves high penetration levels.

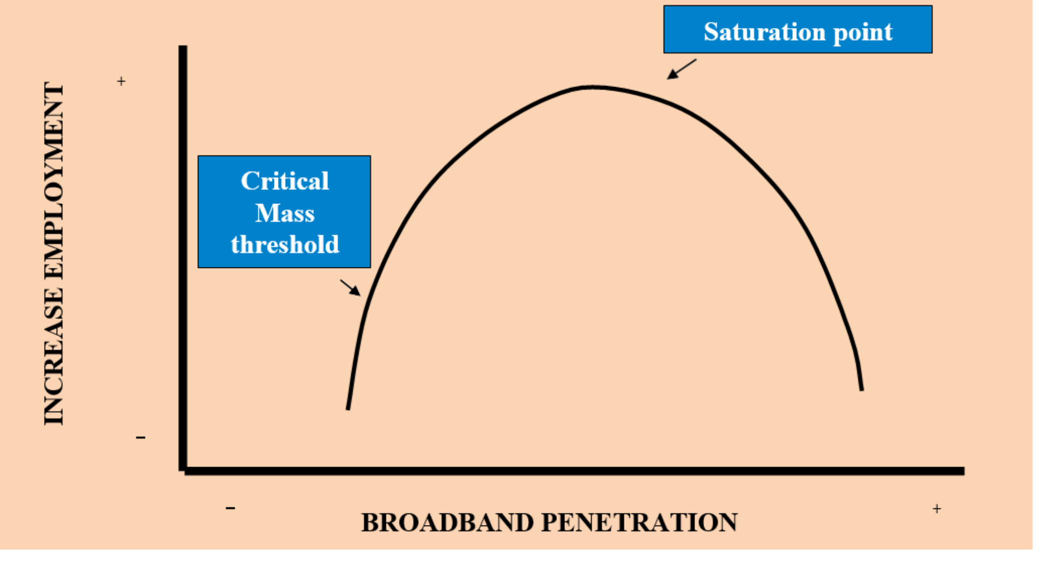

Figure 8: Non-linear (or inverted U shape) relationship between broadband penetration and output

Source: Impact of broadband on the economy (ITU)

Theoretically, it appears that there is a non-linear (or inverted U shape) relationship between broadband penetration and output. At low levels of broadband penetration, we believe the impact of broadband on the economy is minimal due to the "critical mass" concept. According to the "return to scale" theory, the impact of telecommunications infrastructure on the economic output is maximized once the infrastructure reaches a critical mass point, generally associated with levels of penetration of developed countries. The implication of this finding for developing countries is significant. Research points to the fact that in order to achieve an important level of economic impact, broadband needs to reach high levels of penetration. For example, (Koutroumpis 2009)[6] found that for OECD countries the contribution of broadband to OECD economic growth increased with penetration.

According to Koutroumpis' research, in countries with low broadband penetration (under 20%), an increase of 1 per cent in broadband adoption contributes to 0.008 per cent of GDP growth, while in countries with medium penetration (between 20% and 30%), the effect is of 0.014 per cent and in countries with penetration higher than 30 per cent, the impact of 1 per cent adoption reaches 0.023. The implication of this finding for developing countries is quite significant. Unless emerging economies do not strive to dramatically increase their penetration of broadband, the economic impact of the technology will be quite limited.

At the other end of the penetration process, some authors have already pointed out a potential “saturation” effect. They find that beyond a certain adoption level (not specified, as of yet), the effect of broadband on the economy tends to diminish. For example, Atkinson at al. (2009)[2] point out that network externalities decline with the build out of networks and the maturation of technology over time. There is evidence that supports this argument. It has been demonstrated in diffusion theory that early technology adopters are generally those who can elicit the higher returns of a given innovation. Conversely, network externalities would tend to diminish over time because those effects would not be as strong for late adopters.

2.1.2 Broadband studies and the endogeneity problem

Similarly, to the studies on the effects of telecommunication services (computer, mobile telephony and broadband penetration) on economic outputs, the estimated regressions of the model between broadband speed and economic outputs, such as GDP, are likely to suffer from endogeneity bias. The main concern of the endogeneity problem is a reverse causality. While most studies aim to capture the effects of telecommunication services on economic outputs, the development of telecommunication service could depend on economic development, especially in countries with high income, which tend to invest more in telecommunication sectors due to the demand of their citizens. Another endogeneity bias could come from government intervention in the telecommunication sector because the intervention could also rely on the economic development of the country (Czernich et al., 2011)[7].

In the past decades, many scholars have therefore applied different models to capture these endogeneity biases. Most studies adopted two-stage or three-stage least squares (2SLS or 3SLS) and used the predicted values of variables to solve or reduce these endogeneity biases.

To test the saturation hypothesis, Czernich et al. (2009)[7] added dummy variables to account for 10 per cent and 20 per cent broadband penetration to their models. They found that 10 per cent broadband penetration has a significant impact on GDP per capita: between 0.9 and 1.5 percentage points. Similarly, in their study of the state of Kentucky, Shideler et al. (2007)[8] estimated that employment growth is highest around the mean level of broadband saturation at the county level, driven by the diminishing returns to scale of the infrastructure. According to this, a critical amount of broadband infrastructure may be needed to sizably increase employment, but once a community is completely built out, additional broadband infrastructure will not further affect employment growth.

The saturation evidence still needs to be carefully tested particularly in terms of what the optimal point is beyond which broadband exhibits decreasing economic returns. For example, in a study conducted in Germany, it was not possible to identify a saturation point for broadband penetration. Furthermore, even if that were to be found confirming evidence of saturation about contribution to GDP or employment creation, that would not put into question the need to achieve universal broadband in terms of the social benefits it yields to end users.

Most of the statistical research on the economic impact on GDP growth is performed using regressions of cross-lagged indicators (in other words, an increase in broadband deployment in year one is found to have an impact two or more years later). This approach is common in the assessment of economic impact of infrastructure (given that no deployment has an immediate economic impact.) However, the premise underlying the lagged effects assumption comprises a more complicated process of broadband adoption.

Management science has studied how technology is adopted by individual firms and how it impacts firm productivity. First, purchasing ICT is not the only requirement for improving productivity. In fact, both management and economics literature have shown that it is necessary to modify business practices for information technology impact firm efficiency. Accordingly, independently from the pace at which ICT is being adopted, the impact on efficiency and productivity is driven by what has been called “accumulation of intangible capital”. This effect that has been studied for ICT exists in the case of broadband as well. Technology adoption is only the first step in the assimilation of business processes that yield improvement in productivity.

To sum up, in order to fully increase efficiency and output, the adoption of information and communication technologies by enterprises requires the introduction of a number of processes and organizational changes. These changes, as well as training and other cultural factors, (such as entrepreneurial spirit, willingness to take risks in an organizational transformation), are referred to as the accumulation of intangible capital. Broadband does not in itself have an economic impact. It represents an enabler for the adoption of e-business processes that result in increased efficiency (such as streamlined access to raw materials and management of the supply chain, or better market access). Intangible capital accumulation and the adoption of e-business processes delay the full economic impact of broadband.

Lagged effects are neither uniform nor permanent. They are most marked at the start of broadband deployment. It stands to reason that once firms have undergone the transformation required to enable the full impact of broadband, further deployment of the technology should have an immediate impact. Finally, van der Ark et al. (2002)[9] note that institutional variables such as labor market regulation could also have a significant impact on models that link broadband and productivity. The public policy implications of this effect cannot be understated. To achieve full economic benefit of broadband deployment, governments need to emphasize the implementation of training programs and, in the case of SMEs, offer consulting services that help firms capture the full benefit of the technology.

Studies on the impacts of telecommunications infrastructure and services on economic growth have been conducted several times in the past few decades. One of the earlier studies is Hardy (1980)[10]. The author used cross-sectional time series data for 60 countries and found that telephones can contribute to economic development. Later, more research was conducted on different ICT infrastructures and services. Another interesting study in the 2000s is Röller and Waverman (2001)[11]. The authors applied a simultaneous approach to investigate how ICT infrastructure affects economic growth. In fact, the authors found a causal relationship between ICT infrastructure and GDP. More importantly, this simultaneous approach has since been applied to the case of broadband penetration in Koutroumpis (2009)[5] and mobile telecommunication diffusion in Gruber and Koutroumpis (2011)[12]. In Koutroumpis (2009)[5], the author suggested that higher broadband adoption and use significantly increase economic outputs. The effects are also higher in countries with higher penetration, such as the Scandinavian countries. In a similar way, Gruber and Koutroumpis (2011)[12] found that mobile diffusion has significant positive impacts on economic growth. The impacts are also greater in countries with higher mobile penetration. There are also several studies on broadband infrastructure and services from the 2000s and 2010s.

Besides the simultaneous approach in previous sub-sections, there are several studies that aim to identify the impact of broadband on economic growth with different methods in the past decade. Lehr et al. (2005)[13] estimated the broadband penetration impacts in the US. The authors transformed the economic outputs into a growth variable, using control variables to separate the effects of broadband. Their findings support the idea that broadband stimulates economic growth. Rohman and Bohlin (2012)[4] were among the first who estimated the impact of broadband speed on economic outputs applying the model by Lehr et al. (2005)[13]. While the coefficient of broadband speed in their findings was not significant, the square of the coefficient of broadband speed was positively significant. The authors then concluded that doubling the broadband speed contributes 0.3% of GDP growth. Other interesting studies on broadband infrastructure and economic growth in the past few years include Czernich et al. (2011)[6] and Thompson Jr. and Garbacz (2011)[14]. Czernich et al. (2011)[6] applied instrumental variable estimation and found that increasing the broadband penetration rate by 10% stimulates GDP per capita by 0.9-1.5%. Thompson Jr. and Garbacz (2011)[14] divided broadband impacts into direct and indirect impacts. For the direct impacts, the authors applied a fixed effect on panel data with adjustments for endogeneity, while the stochastic frontier production function was used for the indirect impacts.

Nevertheless, broadband connectivity on its own cannot fully explain its great impact on economic outputs. Currently, the speed and quality of broadband vary across countries. Middleton (2013)[15] mentioned that there are more characteristics to consider for broadband networks such as speed, type of connection, quality of service and service provider. This study may not cover all the characteristics of broadband networks; however, it analyzed the speed issue, which few studies have done so far. With regard to literature related to broadband speed, only a handful of studies have been conducted. Rohman and Bohlin (2012 and 2013)[4] analyzed impacts of broadband speed on GDP per capita for a macro-level study and household income in a micro-level study. At macro-level, the authors found that doubling the speed in the OECD countries encouraged 0.3% GDP growth compared with the base year. At micro-level, the authors suggested that OECD countries can obtain benefits at household level from broadband when the broadband speed capacity is at least in the range of 2-4 Mbps. Furthermore, some studies imply that the higher speed contributes to better economic impacts. Katz et al. (2010)[3] analysed the national broadband plan for Germany and suggested that if Germany achieve both the broadband penetration and speed targets, there will be more than 960,000 additional jobs and output worth more than 170 billion euro. Forzati and Mattsson (2012)[16] analysed the impacts of job employment from the area with fibre access. The authors concluded that the increase in the ratio of the population that lives within 353 metres of a fibre-connected premise contributes positively to job employment from 0%-0.2% after two and a half years.

Czernich et al. (2011)[7] measure broadband adoption as the number of broadband subscribers per 100 inhabitants and investigate its influence on economic growth with panel data for 25 OECD countries from 1996 to 2007. The authors apply a two-stage instrumental variable approach in which the rate of broadband adoption is estimated in the first stage through non- linear least squares based on a logistic diffusion model. Subsequently the estimated broadband penetration rates are employed as broadband variables in two second-stage models: in the first model, broadband introduction is used as a dummy variable in difference-in-differences estimations with fixed effects; in the second model, the broadband adoption rate is used as a continuous variable in a static cross-country growth model with fixed effects. The authors find that broadband introduction increases per capita growth significantly such that the GDP per capita after the introduction of broadband was 2.7 to 3.9 percent higher than before. A 10-percentage point increase in the broadband adoption rate increases the annual per capita growth by 0.9 to 1.5 percentage points. The authors also find evidence for a critical mass phenomenon at a broadband adoption rate of 10 percent.

Thompson and Garbacz (2011)[14] evaluate the impact of mobile and fixed broadband adoption on economic growth utilizing panel data for 43 countries from 2005 to 2009. Fixed-effect instrumental variable regressions are applied in which static equations are estimated for high and low income countries individually and combined. In all specifications, the authors find that mobile broadband has a significant positive impact on GDP per household. However, the magnitude of this impact is larger in low income countries. In contrast, the coefficient for fixed broadband is negative but marginally significant in low income countries only.

Arvin and Pradhan (2014)[17] establish a causal relationship between broadband adoption and economic growth employing panel data from 1998 to 2011 for 19 of the former G20 countries which are subsequently divided into developed and developing (‘emerging’) countries. Based on static and dynamic regressions that include variables for GDP, the number of broadband users, the degree of urbanization and the real inflow of foreign direct investment, the authors apply panel cointegration and Granger causality tests to verify causal relationships. Initially, cointegration is found between all four variables suggesting long-run causal relationships between these variables. In contrast to that, the Granger causality tests do not provide evidence for any kind of long-run causal relationship between GDP and broadband penetration. In the short run, the authors find that a bidirectional causal relationship between economic growth and broadband penetration exists only for developed countries; in developing countries, only economic growth causally impacts broadband penetration.

Gruber et al. (2014)[18] use data for 27 European Union (EU) countries from 2005 to 2011 to evaluate the benefits and costs of the Digital Agenda for Europe (DAE). To estimate the return parameters of broadband infrastructure, the authors set up a simultaneous equations model, similar to Röller and Waverman (2001)[12], and apply fixed-effect three-stage least squares regressions. The estimates suggest that broadband adoption rates had a significant positive effect on GDP in the observed period. Moreover, the results indicate that this effect is significantly larger for a broadband adoption rate greater than 15 percent.

2.2 Conclusions on literature review

Overall, four out of five studies that examine the impacts of broadband adoption on GDP and GDP growth with country-level data find a positive and significant effect. Arvin and Pradhan (2014)[17] represents the only study with inconclusive results on the relationship between broadband and GDP. Contrary to that, the clear results in the other studies ascertain that broadband adoption indeed causes GDP growth. Given that two of the cross-country studies provide evidence for a critical mass or a stronger influence of broadband in developed countries, the impact should, however, not be assumed to be linear but rather to be increasing in the penetration rate of a country. Moreover, it seems to be necessary for countries with low broadband penetration to reach a certain penetration level if they want to experience the largest possible benefits of broadband.

3. The model

This report replicates the model set out in the Koutroumpis (2018)[19] paper. The model is based on an aggregate production function which links national aggregate economic output GDP_{it} to a set of production factors in each country i at time t. In particular, the stock of capital (K), labor (L) and the stock of broadband and fixed telecommunications infrastructure. The stock of broadband infrastructure is used rather than the broadband investment because consumers demand infrastructure and not investment per se. Since the expected growth effects deriving from broadband accrue from the use of the infrastructure. I approximate these effects through the level of broadband adoption (BB_Pen).

To maintain the momentum once broadband adoption reaches a saturation point, the intensive margin of the infrastructure must be exploited through improvements in quality that enable the use of a wider range of services. For a broadband speed variable is added in the production function to assess the variations in quality of broadband access on GDP. Speed is not strictly exogenous as wealthier countries may indeed have higher quality of connections. To proceed with this analysis, it is assumed that any reverse effect from GDP on speed is largely absorbed by the adoption variable. The production function now becomes:

3.1 Aggregate production function

The aggregate production function equation is the following:

$$\log(GDP_{it}) = a_1 \log(K_{it}) + a_2 \log(L_{it}) + a_3 \log(BBPen_{it}) + a_4 \log(BB\_Speed_{it}) + \varepsilon_1 \quad (1)$$

Real GDP thus is a function of labor force, capital stock and broadband infrastructure. While the coefficients for labor (L) and capital (K) should be typical for production functions, the coefficient of broadband penetration in equation (1) estimates the one-way causal relationship flowing from the stock of broadband telecommunications infrastructure to aggregate GDP. In order to disentangle the possible effects of broadband telecommunications infrastructure on GDP from the effects of GDP on broadband telecommunications infrastructure, I specify a micro-model for the telecommunications sector in each country consisting of an equation for demand of broadband infrastructure.

3.2 Demand for broadband infrastructure

The demand for broadband infrastructure equation is the following:

$$BB\_Pen_{it} = g(GDPC_{it}, BBPr_{it}, EDU_{it}, RD_{it}, Urb_{it}) \quad (2)$$

The demand equation (2) links broadband penetration as a function of **GDP per capita (GDPC)**, the price of the broadband service (**BBPr**) and other parameters that affect the propensity to adopt broadband technologies, namely **the percent of GDP invested in education** in country i, the percent of **GDP** invested in research and development **(R&D)** and the level of **urbanization (Urb)**.

Figure 9 correlates the average number of percent of GDP invested in research and development in the countries mentioned above with the average level of broadband diffusion in a yearly basis from 2012 to 2017.

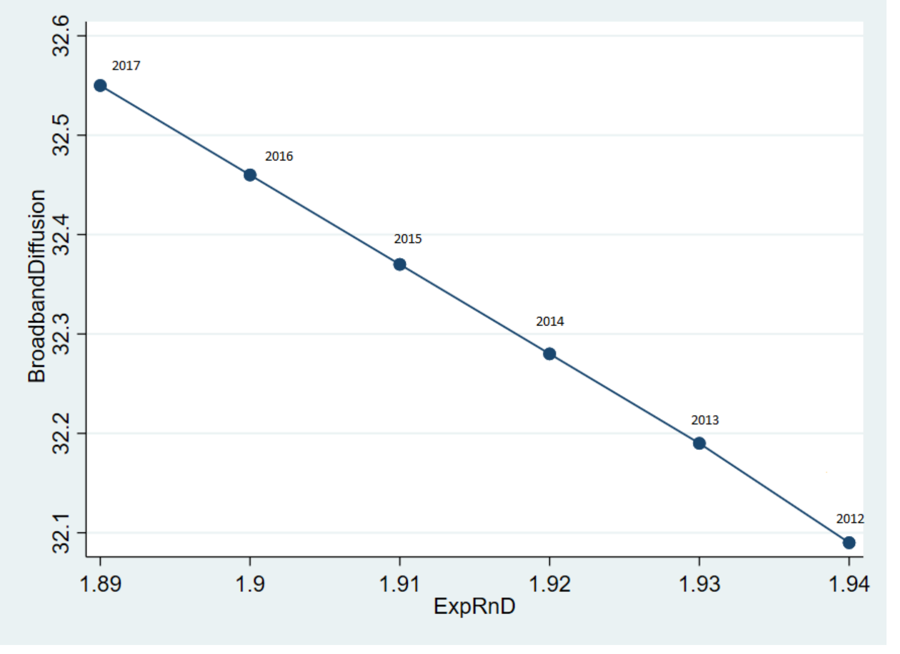

Figure 9: Expenditure in research and development / Broadband Diffusion correlation

Figure 10 correlates the average number of GDP Per Capita in the countries mentioned above with the average level of broadband diffusion in a yearly basis from 2012 to 2017.

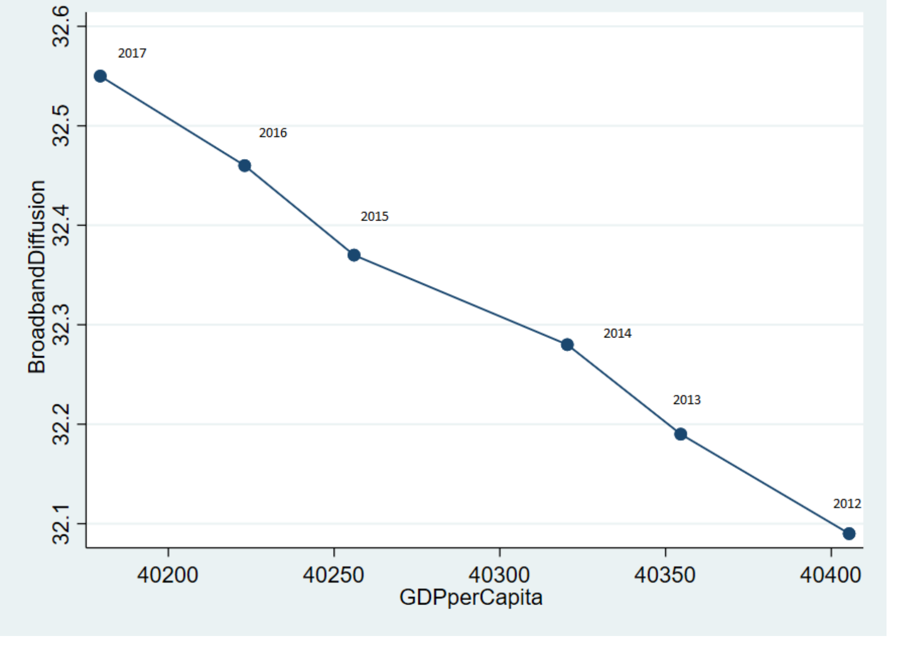

Figure 10: GDP Per Capita / Broadband Diffusion correlation

Figure 11 correlates the average number of urban population in the countries mentioned above with the average level of broadband diffusion in a yearly basis from 2012 to 2017.

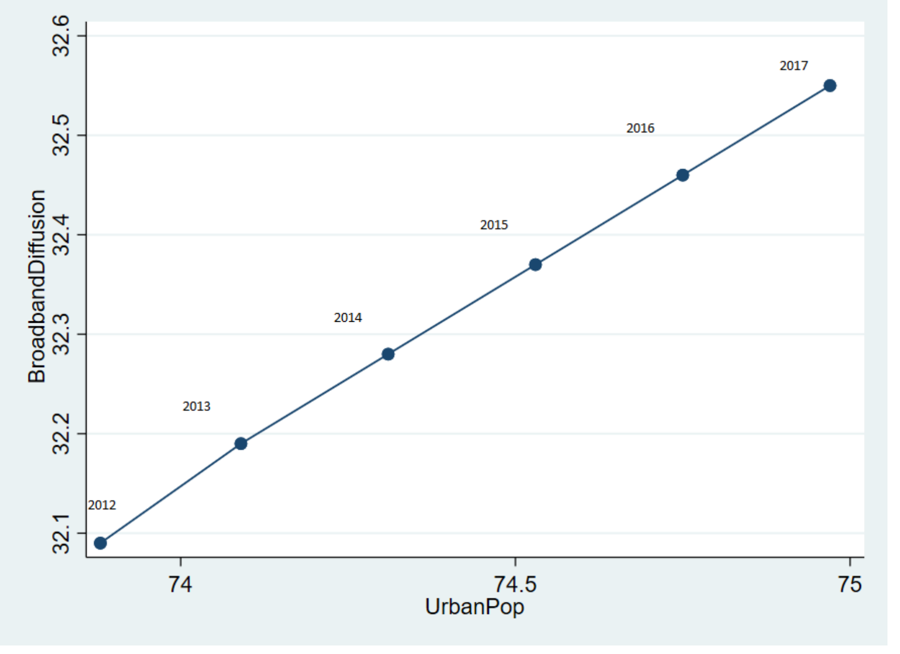

Figure 11: Urban Population / Broadband Diffusion correlation

Figure 12 correlates the average number of gross capital formation in the countries mentioned above with the average level of GDP in constant 2010 US Dollars in a yearly basis from 2012 to 2017.

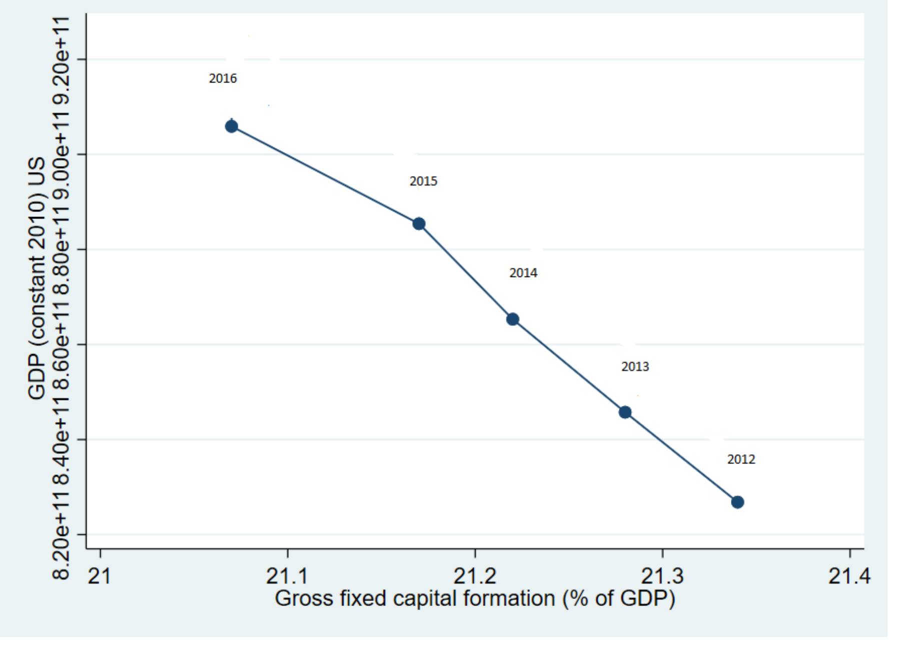

Figure 12: Gross fixed capital formation / GDP correlation

Figure 13 correlates the average number of fitted broadband penetration in the countries mentioned above with the average level of GDP in constant 2010 US Dollars in a yearly basis from 2012 to 2017.

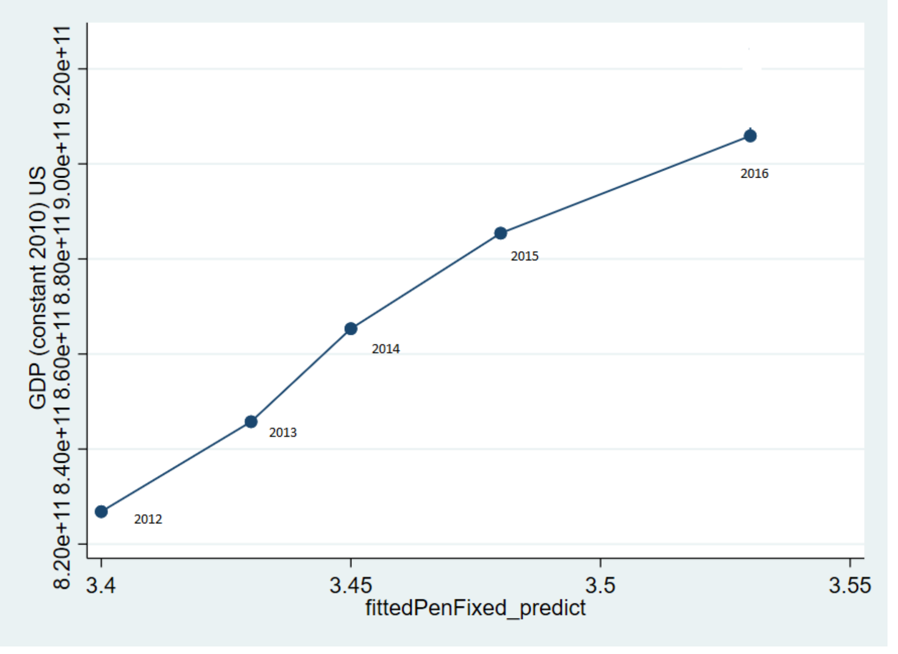

Figure 13 : Fitted Broadband Penetration / GDP correlation

Figure 14 correlates the average number of average speed in the countries mentioned above with the average level of GDP in constant 2010 US Dollars in a yearly basis from 2012 to 2017.

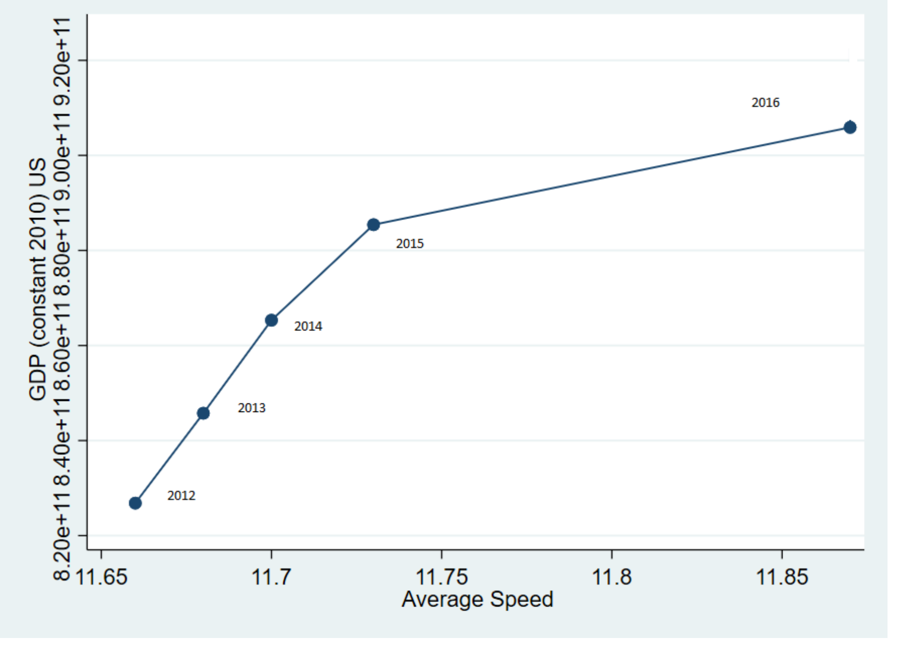

Figure 14 : Average speed / GDP correlation

Figure 15 correlates the average number of labor in the countries mentioned above with the average level of GDP in constant 2010 US Dollars in a yearly basis from 2012 to 2017.

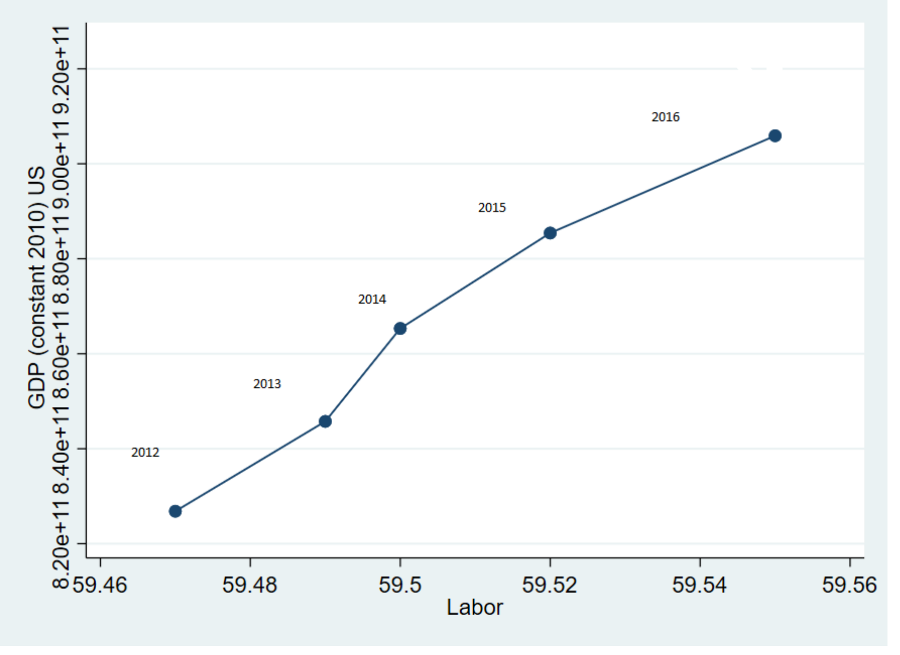

Figure 15: Labor / GDP correlation

4. Data

Building on the work of the previous study, the dataset used in this study consists of annual observations from 20 countries for the five-year period between 2012 and 2017. The countries included in the analysis used are listed in Table 1. The data used have been collected by various sources depending on their nature and availability (see Table 2).

Table 1. Countries included in the analysis

Austria
Belgium
Czech Republic
Denmark
Finland
France
Germany
Hungary
Iceland
Italy
Netherlands
Norway
Poland
Portugal
Romania
Slovakia
Spain
Sweden

Switzerland
United Kingdom

Table 2. Data used in the analysis and sources

Variables	**Source**
GDP (constant 2010 US$)	World Bank
GDP per capita (constant 2010 US$)	World Bank
Gross fixed capital formation (% of GDP)	World Bank
Fixed broadband subscriptions (per 100 people)	ITU
Fixed broadband Internet monthly subscription (US$)	ITU
Urban population (% of total)	ITU
Government expenditure on education, total (% of GDP)	ITU
Research and development expenditure (% of GDP)	ITU
Fixed (wired)-broadband speed; in Mbits/s	Akamai Reports
Labour force participation rate, total (% of total population ages 15+) (modeled ILO estimate)	World Bank

5. Panel Data Analysis Results

The two most common approaches regarding panel data regression are the fixed effects model and the random effects model. The key difference between these two approaches is how we believe the individual error component behaves. Another approach is dynamic panel data analysis like Generalized Method of Moments which uses moment conditions in which lags of the dependent variable and first differences of the exogenous variables are instruments for the first-differenced equation.

Endogeneity problem and GMM

Antonakis et al. (2014)[21] argue that results of studies which do not address problems of endogeneity may be misleading for understanding phenomena. Accurate information cannot be extracted about the causal relationship between dependent and independent variables. Therefore, we tackle endogeneity with a popular method known as the generalized method of moments (GMM). An advantage of this approach is that it does not make any distributional assumption. A set of instruments must be chosen that has to be correlated with the endogenous regressors. It is also necessary to employ at least as many instruments as the number of endogenous regressors and they cannot be the same. The choice of instruments is important. If instruments are weak, then the sampling distributions of GMM statistics are in general non-normal and standard GMM point estimates, hypothesis tests, and confidence intervals are unreliable. To make sure the instruments are not weak we perform the Cragg and Donald (1993)[22] test in untabulated results. The null hypothesis of weak instruments is rejected allowing us to cautiously conclude that GMM confidence intervals are reliable.

5.1 The fixed effects model

In the fixed effects model the individual error component:

1. Can be thought of as an individual-specific intercept term.
2. Captures any omitted variables that are not included in the regression.
3. Is correlated with other variables included in the model.

Given these assumptions, the fixed effects model can be thought of as a pooled OLS model with individual specific intercepts:

$$y_{it} = \delta_i + X_{it}\beta + \nu_{it}$$

The intercept term, $\boldsymbol{\delta_i}$, varies across individuals but is constant across time for each individual. This term is composed of the constant intercept term, α, and the individual-specific error terms, $\boldsymbol{\mu_i}$.

The distinguishing feature of the fixed effects model is that $\boldsymbol{\delta_i}$ has a true, but unobservable, effect which we must estimate.

FE explore the relationship between predictor and outcome variables within an entity (country, person, company, etc.). Each entity has its own individual characteristics that may or may not influence the predictor variables. When using FE it is assume that something within the individual may impact or bias the predictor or outcome variables and it is needed to control for this. This is the rationale behind the assumption of the correlation between entity's error term and predictor variables. FE remove the effect of those time-invariant characteristics so the net effect of the predictors on the outcome variable can be assessed. Another important assumption of the FE model is that those time-invariant characteristics are unique to the individual and should not be correlated with other individual characteristics. Each entity is different therefore the entity's error term and the constant (which captures individual characteristics) should not be correlated with the others. If the error terms are correlated, then FE is no suitable since inferences may not be correct and it is needed to model that relationship probably using random effects.

5.2 The random effects model

In the random effects model the individual-specific error component, $\boldsymbol{\mu_i}$:

1. Is distributed randomly and is independent of $\boldsymbol{v_{it}}$.

2. Occurs in cases where individuals are drawn randomly from a large population, such as household studies.

3. Is assumed to be uncorrelated with all other variables in the model.

4. Random effects impact our model through the covariance structure of the error term.

For example, consider the total error disturbance in the model, $\boldsymbol{u_{it}} = \boldsymbol{\mu_i} + \boldsymbol{v_{it}}$. The covariance of the error at time t and time s depends on the variance of both $\boldsymbol{\mu_i}$ and $\boldsymbol{v_{it}}$

$$cov(u_{it}, u_{is}) = \begin{cases} \sigma_\mu^2 & \text{for } t \neq s \\ \sigma_\mu^2 + \sigma_\nu^2 & \text{for } t = s \end{cases}$$

The distinguishing feature of the random effects model is that $\boldsymbol{\mu_i}$ does not have a true value but rather follows a random distribution with parameters that we must estimate.

5.3 Dynamic panel data estimators

Random-effects and fixed-effects panel-data models do not allow to use observable information of previous periods in the used model. They are static. Dynamic panel-data models use current and past information.

For this study, Arellano–Bond estimator xtabond, the most common linear dynamic panel-data estimator is used.

In the context of panel data, we usually must deal with unobserved heterogeneity by applying the within (demeaning) transformation, as in one-way fixed effects models, or by taking first differences if the second dimension of the panel is a proper time series. The ability of first differencing to remove unobserved heterogeneity also underlies the family of estimators that have been developed for dynamic panel data (DPD) models. These models contain one or more lagged dependent variables, allowing for the modeling of a partial adjustment mechanism.

The DPD (Dynamic Panel Data) approach is usually considered the work of Arellano and Bond (AB) (Rev. Ec. Stud., 1991), but they in fact popularized the work of Holtz-Eakin, Newey and Rosen (Econometrica, 1988)[20]. It is based on the notion that the instrumental variables approach noted above does not exploit all of the information available in the sample. By doing so in a Generalized Method of Moments (GMM) context, we may construct more efficient estimates of the dynamic panel data model.

Arellano and Bond argue that the Anderson–Hsiao estimator, while consistent, fails to take all of the potential orthogonality conditions into account. A key aspect of the AB strategy, echoing that of AH, is the assumption that the necessary instruments are 'internal': that is, based on lagged values of the instrumented variable(s). The estimators allow the inclusion of external instruments as well. Consider the equations

$$\begin{aligned} y_{it} &= X_{it}\beta_1 + W_{it}\beta_2 + v_{it} \\ v_{it} &= u_i + \epsilon_{it} \end{aligned}$$

where $\mathbf{X_{it}}$ includes strictly exogenous regressors, $\boldsymbol{W_{it}}$ are predetermined regressors (which may include lags of y) and endogenous regressors, all of which may be correlated with $\boldsymbol{u_i}$, the unobserved individual effect. First-differencing the equation removes the $\boldsymbol{u_i}$ and its associated omitted-variable bias.

The Arellano–Bond estimator sets up a generalized method of moments (GMM) problem in which the model is specified as a system of equations, one per time period, where the instruments applicable to each equation differ (for instance, in later time periods, additional lagged values of the instruments are available).

5.4 Results

5.4.1 Demand equation regression

5.4.1.1 Fixed Effects

Firstly, the demand equation BB_Pen_{it} **=** $g(GDPC_{it}, BBPr_{it}, EDU_{it}, RD_{it}, Urb_{it})$ **(2)** is estimated using panel data regression with fixed effects. Figure 16 shows the results.

```
. xtreg PenLog SubscriptionLog UrbanPopLog GDPperCapitalLog expEducLog expRnDLog, fe

Fixed-effects (within) regression               Number of obs     =        120
Group variable: CountryNum                      Number of groups  =         20

R-sq:                                           Obs per group:
     within  = 0.6190                                         min =          6
     between = 0.5324                                         avg =        6.0
     overall = 0.5042                                         max =          6

                                                F(5,95)           =      30.87
corr(u_i, Xb)  = -0.9897                        Prob > F          =     0.0000

------------------------------------------------------------------------------------
           PenLog |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
------------------+-----------------------------------------------------------------
  SubscriptionLog |  -.0774854   .0293948    -2.64   0.010    -.1358415   -.0191294
      UrbanPopLog |   7.883791    .756746    10.42   0.000      6.38146    9.386122
 GDPperCapitalLog |   .0259647   .0675296     0.38   0.701    -.1080986    .1600279
       expEducLog |   .1302395   .0360479     3.61   0.000     .0586755    .2018035
        expRnDLog |    .053458   .0226162     2.36   0.020     .0085592    .0983568
            _cons |  -30.66798   3.513015    -8.73   0.000     -37.6422   -23.69377
------------------+-----------------------------------------------------------------
          sigma_u |  1.2243585
          sigma_e |  .04717891
              rho |  .99851737   (fraction of variance due to u_i)
------------------------------------------------------------------------------------
F test that all u_i=0: F(19, 95) = 41.06                     Prob > F = 0.0000
```

Figure 16: Panel data analysis fixed effects

Below, the most significant statistics are explained:

Prob>F = 0.000 This is an F-Test to see whether all coefficients in the model are different from zero. If this number is <0.05 then the model is robust.

Corr(u_i, x_b) = -0.9897 The errors u_i are correlated with the regressors in fixed effects model.

t-values - t-values test the hypothesis that each coefficient is different from 0. To rejects this, the t-value has to be higher than 1.96 for a 95% confidence. If this is the case, then you can say that the variable has a significant influence on your dependent variable. The higher the t-value the higher the relevance of the variable.

P > |t| – Two-tail p-values test the hypothesis that each coefficient is different from 0. To reject this, the p-value has to be lower than 0.05.

Table of statistics for each coefficient:

Coefficients	|t-value|	P>|t|
Fixed broadband Internet monthly subscription (US$)	2.64 > 1.96	0.010 < 0.05
Urban population (% of total)	10.42 > 1.96	0.000 < 0.05
GDP Per Capita	0.38 < 1.96	0.700 > 0.05
Government expenditure on education, total (% of GDP)	3.61 > 1.96	0.000 < 0.05
Research and development expenditure (% of GDP)	2.36 > 1.96	0.020 < 0.05

F-Statistic: 30.87

The results show that monthly subscription, urban population (% of total), government expenditure on education and research and development expenditure variables have positive effect on penetration and are statistically significant. Moreover, fixed broadband internet monthly subscription has negative effect as expected and is also statistically significant. GDP Per Capita coefficient is not statistically significant. F-statistic which measures the overall statistical significance of the model indicates that the model is robust.

5.4.1.2 Random Effects

Secondly, the demand equation $BB\_Penit = g(GDPCit , BBPrit , EDUit , RDit, Urbit)$ (2) is estimated using panel data regression with random effects. Figure 17 shows the results.

```
. xtreg PenLog SubscriptionLog UrbanPopLog GDPperCapitalLog expEducLog expRnDLog, re

Random-effects GLS regression                   Number of obs     =        120
Group variable: CountryNum                      Number of groups  =         20

R-sq:                                           Obs per group:
     within  = 0.3138                                         min =          6
     between = 0.5622                                         avg =        6.0
     overall = 0.5391                                         max =          6

                                                Wald chi2(5)      =      57.87
corr(u_i, X)   = 0 (assumed)                    Prob > chi2       =     0.0000

----------------------------------------------------------------------------------
          PenLog |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-----------------+----------------------------------------------------------------
 SubscriptionLog |   -.046223   .0386759    -1.20   0.232    -.1220265    .0295805
     UrbanPopLog |   1.285812   .2474055     5.20   0.000     .8009059    1.770718
GDPperCapitalLog |   .0035852   .0608585     0.06   0.953    -.1156953    .1228656
      expEducLog |   .1386412   .0487902     2.84   0.004     .0430141    .2342682
       expRnDLog |   .0583192   .0303428     1.92   0.055    -.0011516    .1177899
           _cons |  -2.228628   1.007778    -2.21   0.027    -4.203836     -.25342
-----------------+----------------------------------------------------------------
         sigma_u |  .12645419
         sigma_e |  .04717891
             rho |  .87781144   (fraction of variance due to u_i)
----------------------------------------------------------------------------------
```

Figure 17: Panel data analysis random effects

In case of random effects panel data analysis interpretation of the coefficients is tricky since they include both the within-entity and between-entity effects. ***Corr(u_i,X)*** *= 0* (assumed) indicates that differences across units are uncorrelated with the regressors. Two tail p-values test the hypothesis that each coefficient is different from 0. To reject this, the **p-value** must be lower than 0.05%. If this is the case, then you can say that the variable has a significant influence on the dependent variable.

Below, the most significant statistics are explained:

Wald chi2 - This is the Wald Chi-Square statistic. It is used to test the hypothesis that at least one of the predictors' regression coefficient is not equal to zero. The number in the parentheses indicates the degrees of freedom of the Chi-Square distribution used to test the Wald Chi-Square statistic and is defined by the number of predictors in the model.

Prob > chi2 – This is the probability of getting a Wald test statistic as extreme as, or more so, than the observed statistic under the null hypothesis; the null hypothesis is that all the regression coefficients across both models are simultaneously equal to zero. In other words, this is the probability of obtaining this chi-square statistic (89.85) or one more extreme if there is in fact no effect of the predictor variables. This p-value is compared to a specified alpha level, our willingness to accept a type I error, which is typically set at 0.05 or 0.01. The small p-value from the test, <0.0001, would lead us to conclude that at least one of the regression coefficients in the model is not equal to zero. The parameter of the chi-square distribution used to test the null hypothesis is defined by the degrees of freedom in the prior line, chi2.

_cons – This is the regression estimate when all variables in the model are evaluated at zero. For a male student (the variable female evaluated at zero) with langscore and mathscore of zero, the predicted achievement score is -0.2940047. Note that evaluating langscore and mathscore at zero is out of the range of plausible test scores.

Std. Err. – These are the standard errors of the individual regression coefficients. They are used in both the calculation of the z test statistic, superscript l, and the confidence interval of the regression coefficient, superscript n.

z – The test statistic z is the ratio of the coefficient to the standard error of the respective predictor. The z value follows a standard normal distribution which is used to test against a two-sided alternative hypothesis that the coefficient is not equal to zero. To rejects this, the z-value must be higher than 1.96 for a 95% confidence.

P>|z| – This is the probability the z test statistic (or a more extreme test statistic) would be observed under the null hypothesis that a particular predictor's regression coefficient is zero, given that the rest of the predictors are in the model. For a given alpha level, P>|z| determines whether or not the null hypothesis can be rejected. If P>|z| is less than alpha, then the null hypothesis can be rejected and the parameter estimate is considered statistically significant at that alpha level.

_cons – The z test statistic for the intercept, _cons, is (-0.2940047/6.204858) = -0.05 with an associated p-value of 0.962.

[95% Conf. Interval] – This is the Confidence Interval (CI) for an individual coefficient given that the other predictors are in the model. For a given predictor with a level of 95% confidence, we'd say that we are 95% confident that the "true" coefficient lies between the lower and upper limit of the interval. It is calculated as the Coef. (zα/2)*(Std.Err.), where zα/2 is a critical value on the standard normal distribution. The CI is equivalent to the z test statistic: if the CI includes zero, we'd fail to reject the null hypothesis that a regression coefficient is zero given the other predictors are in the model. An advantage of a CI is that it is illustrative; it provides a range where the "true" parameter may lie.

/sigma – This is the estimated standard error of the regression. In this example, the value, 7.739053, is comparable to the root mean squared error that would be obtained in an OLS regression. If we ran an OLS regression with the same outcome and predictors, our RMSE would be 6.8549. This is indicative of how much the outcome varies from the predicted value. /sigma approximates this quantity for truncated regression.

Table of statistics for each coefficient:

Coefficients	**|z|**	**P>|z|**
Fixed broadband Internet monthly subscription (US$)	1.20 < 1.96	0.232 > 0.05
Urban population (% of total)	5.20 > 1.96	0.000 < 0.05
GDP Per Capita	0.06 < 1.96	0.953 > 0.05
Government expenditure on education, total (% of GDP)	2.84 > 1.96	0.004 < 0.05
Research and development expenditure (% of GDP)	1.91 > 1.96	0.055 > 0.05

Prob > chi2: 0.000 < 0.05

In our analysis, we can conclude that urban population, expenditure on education and RnD have significant impact on broadband penetration and are statistically significant. Wald chi indicator is an F test to check whether all the coefficients in the model are different than zero. If this number is <0.05 then the model is robust and in our case this is true.

5.4.1.3 Generalized Method of Moments

Figure 18 shows the results of Arellano-Bond dynamic panel-data estimation.

```
Arellano-Bond dynamic panel-data estimation     Number of obs      =         80
Group variable: CountryNum                      Number of groups   =         20
Time variable: YearNum
                                                Obs per group:
                                                              min =          4
                                                              avg =          4
                                                              max =          4

Number of instruments =     16                  Wald chi2(6)       =    1106.47
                                                Prob > chi2        =     0.0000
One-step results
```

PenLog	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
PenLog						
L1.	.8666801	.0523729	16.55	0.000	.7640311	.9693291
SubscriptionLog	.0013352	.0114383	0.12	0.907	-.0210835	.0237538
UrbanPopLog	.6591249	.5418202	1.22	0.224	-.4028231	1.721073
GDPperCapitalLog	.014997	.0273488	0.55	0.583	-.0386057	.0685996
expEducLog	-.0164103	.0149795	-1.10	0.273	-.0457696	.012949
expRnDLog	.0206131	.0087383	2.36	0.018	.0034863	.0377399
_cons	-2.483033	2.22862	-1.11	0.265	-6.851049	1.884982

```
Instruments for differenced equation
        GMM-type: L(2/.).PenLog
        Standard: D.SubscriptionLog D.UrbanPopLog D.GDPperCapitalLog
                  D.expEducLog D.expRnDLog
Instruments for level equation
        Standard: _cons
```

Figure 18: Panel data analysis – Generalized Method of Moments

In the Arellano–Bond framework, the value of the dependent variable in the previous period is a predictor for the current value of the dependent variable. Stata includes the value of the dependent variable in the previous period. Another noteworthy aspect that appears in the table is the mention of 16 instruments in the header. This is followed by a footnote that refers to GMM and standard-type instruments. The relationship of interest is given by

$$y_{it} = x'_{it}\beta_1 + y_{i(t-1)}\beta_2 + \alpha_i + \varepsilon_{it}$$

In the equation above, y_{it} is the outcome of interest for individual i at time t, x_{it} are a set of regressors that may include past values, $y_{i(t-1)}$ is the value of the outcome in the previous period, α_i is a time-invariant unobservable, and ε_{it} is a time-varying unobservable.

As in the fixed-effects framework, we assume the time-invariant unobserved component is related to the regressors. When unobservables and observables are correlated, we have an endogeneity problem that yields inconsistent parameter estimates if we use a conventional linear panel-data estimator. One solution is taking first-differences of the relationship of interest. However, the strategy of taking first-differences does not work. Why?

$$\Delta y_{it} = \Delta x'_{it}\beta_1 + \Delta y_{i(t-1)} + \Delta\varepsilon_{it}$$
$$E\left(\Delta y_{i(t-1)}\Delta\varepsilon_{it}\right) \neq 0$$

In the first equation above, we got rid of α_i, which is correlated with our regressors, but we generated a new endogeneity problem. The second equation above illustrates one of our regressors is related to our unobservables. The solution is instrumental variables. Which instrumental variables? Arellano–Bond suggest the second lags of the dependent variable and all the feasible lags thereafter. This generates the set of moment conditions defined by

$$\begin{aligned} E\left(\Delta y_{i(t-2)}\Delta\varepsilon_{it}\right) &= 0 \\ E\left(\Delta y_{i(t-3)}\Delta\varepsilon_{it}\right) &= 0 \\ &\dots \\ E\left(\Delta y_{i(t-j)}\Delta\varepsilon_{it}\right) &= 0 \end{aligned}$$

In our example, we have 6 time periods, which yield the following set of instruments:

$$\begin{array}{ll} t = 6 & y_{t-4}, y_{t-3}, y_{t-2}, y_{t-1} \\ t = 5 & y_{t-3}, y_{t-2}, y_{t-1} \\ t = 4 & y_{t-2}, y_{t-1} \\ t = 3 & y_{t-1} \end{array}$$

This gives us 16 instruments which are what the table calls GMM-type instruments. The other instruments are given by the first difference of the regressors and the constant. This is no different from two-stage least squares, where we include the exogenous variables as part of our instrument list.

Below, the most significant statistics are explained:

Wald chi2 = 1106.47

This is the Wald Chi-Square statistic. It is used to test the hypothesis that at least one of the predictors' regression coefficient is not equal to zero.

Prob > chi2 = 0.000

This is the probability of getting a Wald test statistic as extreme as, or more so, than the observed statistic under the null hypothesis; the null hypothesis is that all the regression coefficients across both models are simultaneously equal to zero. This p-value is compared to a specified alpha level, our willingness to accept a type I error, which is typically set at 0.05 or 0.01. The small p-value from the test, <0.0001, would lead us to conclude that at least one of the regression coefficients in the model is not equal to zero. The parameter of the chi-square distribution used to test the null hypothesis is defined by the degrees of freedom in the prior line, chi2.

Table of statistics for each coefficient:

Coefficients	**|z|**	**P>|z|**
Fixed broadband Internet monthly subscription (US$)	0.12 < 1.96	0.907
Urban population (% of total)	1.222 < 1.96	0.224
GDP Per Capita	0.55 < 1.96	0.583
Government expenditure on education, total (% of GDP)	1.10 < 1.96	0.273
Research and development expenditure (% of GDP)	2.36 > 1.96	0.018

In this analysis, most of the coefficients re not statistically significant.

5.4.2 Aggregate production function regression (Average speed)

5.4.2.1 Fixed Effects

Afterwards, the aggregate production function $\log(GDPit) = a1\ \log(Kit) + a2\ \log(Lit) + a3\ \log(BBPenit) + a4\log(BB\_Speedit) + \varepsilon1\ (1)$ is estimated using panel data regression. The equation is estimated both for average broadband speed and peak broadband speed. Figure 19 shows the results using panel data regression with fixed effects when average broadband speed is taken into consideration. Penetration, average speed and capital stock have positive effects on output and are statistically significant. F- statistic also indicates that the model is robust.

```
. xtreg GDPLog fittedPenFixed_predict AverageSpeedLog CapitalLog LaborLog, fe

Fixed-effects (within) regression               Number of obs      =       120
Group variable: CountryNum                      Number of groups   =        20

R-sq:                                           Obs per group:
     within  = 0.6005                                         min =         6
     between = 0.2091                                         avg =       6.0
     overall = 0.2090                                         max =         6

                                                F(4,96)            =     36.07
corr(u_i, Xb)  = 0.2418                         Prob > F           =    0.0000

-----------------------------------------------------------------------------------------
                 GDPLog |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
------------------------+----------------------------------------------------------------
fittedPenFixed_predict  |   .2060988   .0621361     3.32   0.001     .0827596     .329438
        AverageSpeedLog |   .0576963   .0095974     6.01   0.000     .0386457    .0767469
             CapitalLog |   .1879415   .0588773     3.19   0.002     .0710709    .3048122
               LaborLog |   .2483011   .2545559     0.98   0.332    -.2569884    .7535906
                  _cons |   24.43394   1.037745    23.55   0.000     22.37404    26.49385
------------------------+----------------------------------------------------------------
                sigma_u |  1.1936699
                sigma_e |  .02996786
                    rho |   .9993701   (fraction of variance due to u_i)
-----------------------------------------------------------------------------------------
F test that all u_i=0: F(19, 96) = 8666.85                   Prob > F = 0.0000
```

Figure 19: Panel data analysis – fixed effects

Table of statistics for each coefficient:

Coefficients	**|t-value|**	**P>|t|**
Broadband Penetration	3.32 > 1.96	0.001
Average Speed	6.01 > 1.96	0.000
Capital Stock	10.42 > 1.96	0.002
Labor Stock	0.38 < 1.96	0.332

F-statistic: 36.07

The results show that average speed, capital stock and broadband penetration have positive effect on GDP and are statistically significant. F-statistic which measures the overall statistical significance of the model indicates that the model is robust.

5.4.2.2 Random Effects

Figure 20 shows the results of the same equation using panel data regression with random effects.

```
. xtreg GDPLog fittedPenFixed_predict AverageSpeedLog CapitalLog LaborLog, re

Random-effects GLS regression                   Number of obs      =       120
Group variable: CountryNum                      Number of groups   =        20

R-sq:                                           Obs per group:
     within  = 0.6002                                          min =         6
     between = 0.2095                                          avg =       6.0
     overall = 0.2094                                          max =         6

                                                Wald chi2(4)       =    150.84
corr(u_i, X)   = 0 (assumed)                    Prob > chi2        =    0.0000

------------------------------------------------------------------------------------------
                GDPLog |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-----------------------+------------------------------------------------------------------
fittedPenFixed_predict |   .2219003    .058966     3.76   0.000     .1063291    .3374715
       AverageSpeedLog |   .0562832   .0093774     6.00   0.000     .0379038    .0746625
            CapitalLog |   .1862531   .0581694     3.20   0.001     .0722432    .3002629
              LaborLog |   .2706819   .2506169     1.08   0.280    -.2205183    .7618821
                 _cons |   24.29663   1.058045    22.96   0.000      22.2229    26.37036
-----------------------+------------------------------------------------------------------
               sigma_u |  1.2802804
               sigma_e |  .02996786
                   rho |   .9994524   (fraction of variance due to u_i)
------------------------------------------------------------------------------------------
```

Figure 20: Panel data analysis – random effects

Below, the most significant statistics are explained:

Wald chi2 =150.84

This is the Wald Chi-Square statistic. It is used to test the hypothesis that at least one of the predictors' regression coefficient is not equal to zero.

Prob > chi2 = 0.00

Table of statistics for each coefficient:

Coefficients	**|z|**	**P>|z|**
Broadband Penetration	3.76 > 1.96	0.000 < 0.05
Average Speed	6.00 > 1.96	0.000 < 0.05
Capital Stock	3.20 > 1.96	0.001 < 0.05
Labor Stock	1.08 > 1.96	0.280 > 0.05

The results show that average speed, capital stock, labor stock and broadband penetration have positive effect on GDP and are statistically significant.

5.4.2.3 Generalized Method of Moments

Figure 21 shows the results of Arellano-Bond dynamic panel-data estimation.

```
. xtabond GDPLog fittedPenFixed_predict AverageSpeedLog CapitalLog LaborLog

Arellano-Bond dynamic panel-data estimation     Number of obs      =        80
Group variable: CountryNum                      Number of groups   =        20
Time variable: YearNum
                                                Obs per group:
                                                              min =         4
                                                              avg =         4
                                                              max =         4

Number of instruments =     15                  Wald chi2(5)       =   1547.88
                                                Prob > chi2        =    0.0000
One-step results
------------------------------------------------------------------------------------
                GDPLog |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-----------------------+------------------------------------------------------------
                GDPLog |
                   L1. |   1.003742   .0566788    17.71   0.000     .8926539    1.114831
                       |
fittedPenFixed_predict |   .0876081   .0313561     2.79   0.005     .0261512     .149065
       AverageSpeedLog |   .0167849   .0048395     3.47   0.001     .0072997    .0262701
            CapitalLog |   .0219843   .0295992     0.74   0.458    -.0360291    .0799977
              LaborLog |  -.1945899   .1484377    -1.31   0.190    -.4855224    .0963427
                 _cons |   .3036536   1.339534     0.23   0.821    -2.321785    2.929092
------------------------------------------------------------------------------------
Instruments for differenced equation
        GMM-type: L(2/.).GDPLog
        Standard: D.fittedPenFixed_predict D.AverageSpeedLog D.CapitalLog D.LaborLog
Instruments for level equation
        Standard: _cons

.
```

Figure 21: Panel data analysis – generalized method of moments

Below, you can find the most significant statistics:

Wald chi2 = 1547.88

Prob > chi2 = 0.000 < 0.001

Table of statistics for each coefficient:

Coefficients	**|z|**	**P>|z|**
Broadband Penetration	2.79 > 1.96	0.000 < 0.05
Average Speed	3.47 > 1.96	0.000 < 0.05
Capital Stock	0.74 < 1.96	0.001 < 0.05
Labor Stock	1.31 < 1.96	0.280

The results show that average speed and broadband penetration have positive effect on GDP and are statically significant.

5.4.3 Aggregate production function regression (Peak speed)

5.4.3.1 Fixed Effects

Figure 22 shows the results using panel data regression with fixed effects when peak broadband speed is taken into consideration.

```
. xtreg GDPLog fittedPenFixed_predict PeakSpeedLog CapitalLog LaborLog, fe

Fixed-effects (within) regression               Number of obs      =       120
Group variable: CountryNum                      Number of groups   =        20

R-sq:                                           Obs per group:
     within  = 0.6535                                         min =          6
     between = 0.2121                                         avg =        6.0
     overall = 0.2107                                         max =          6

                                                F(4,96)            =     45.27
corr(u_i, Xb)  = 0.3035                         Prob > F           =    0.0000

------------------------------------------------------------------------------------------
                GDPLog |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-----------------------+------------------------------------------------------------------
fittedPenFixed_predict |   .1535789   .0596549     2.57   0.012     .0351649    .2719928
          PeakSpeedLog |   .0870976   .0116459     7.48   0.000     .0639807    .1102146
            CapitalLog |   .1710695       .055     3.11   0.002     .0618953    .2802437
              LaborLog |   .2121383   .2370395     0.89   0.373    -.2583813     .682658
                 _cons |   24.62527   .9638021    25.55   0.000     22.71214     26.5384
-----------------------+------------------------------------------------------------------
               sigma_u |  1.2142852
               sigma_e |  .02790633
                   rho |  .99947212   (fraction of variance due to u_i)
------------------------------------------------------------------------------------------
F test that all u_i=0: F(19, 96) = 9991.55                   Prob > F = 0.0000
```

Figure 22: Panel data analysis – fixed effects

Table of statistics for each coefficient:

Coefficients	**|t-value|**	**P>|t|**
Broadband Penetration	2.57 > 1.96	0.012 < 0.05
Peak Speed	7.48 > 1.96	0.000 < 0.05
Capital Stock	3.11 > 1.96	0.002 < 0.05
Labor Stock	0.89 < 1.96	0.337 > 0.05

F-statistic = 45.27

The results show that peak speed, capital stock and broadband penetration have positive effect on GDP and are statistically significant. F-statistic which measures the overall statistical significance of the model indicates that the model is robust.

5.4.3.2 Random Effects

Figure 23 shows the results of the same equation using panel data regression with random effects.

```
. xtreg GDPLog fittedPenFixed_predict PeakSpeedLog CapitalLog LaborLog, re

Random-effects GLS regression                   Number of obs     =        120
Group variable: CountryNum                      Number of groups  =         20

R-sq:                                           Obs per group:
     within  = 0.6532                                         min =          6
     between = 0.2126                                         avg =        6.0
     overall = 0.2117                                         max =          6

                                                Wald chi2(4)      =     187.08
corr(u_i, X)   = 0 (assumed)                    Prob > chi2       =     0.0000

------------------------------------------------------------------------------------------
                GDPLog |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-----------------------+------------------------------------------------------------------
fittedPenFixed_predict |   .1725784   .0568878     3.03   0.002     .0610804    .2840764
          PeakSpeedLog |   .0848422    .011392     7.45   0.000     .0625142    .1071701
            CapitalLog |   .1695073   .0544711     3.11   0.002     .0627459    .2762688
              LaborLog |   .2338629   .2340242     1.00   0.318    -.2248161     .692542
                 _cons |   24.48431   .9910871    24.70   0.000     22.54182    26.42681
-----------------------+------------------------------------------------------------------
               sigma_u |  1.2810511
               sigma_e |  .02790633
                   rho |  .99952569   (fraction of variance due to u_i)
------------------------------------------------------------------------------------------
```

Figure 23: Panel data analysis – random effects

Below, the most significant statistics:

Wald chi2 = 1547.88

Prob > chi2 = 0.000 < 0.001

Table of statistics for each coefficient:

Coefficients	**|z|**	**P>|z|**
Broadband Penetration	3.03 > 1.96	0.002 < 0.05
Peak Speed	7.45 > 1.96	0.000 < 0.05
Capital Stock	3.11 > 1.96	0.002 < 0.05
Labor Stock	1.00 < 1.96	0.318 > 0.05

The results show that peak speed, capital stock and broadband penetration have positive effect on GDP and are statistically significant.

5.4.3.3 Generalized Method of Moments

Figure 24 shows the results of Arellano-Bond dynamic panel-data estimation.

```
. xtabond GDPLog fittedPenFixed_predict PeakSpeedLog CapitalLog LaborLog

Arellano-Bond dynamic panel-data estimation     Number of obs     =        80
Group variable: CountryNum                      Number of groups  =        20
Time variable: YearNum
                                                Obs per group:
                                                              min =         4
                                                              avg =         4
                                                              max =         4

Number of instruments =     15                  Wald chi2(5)      =   1876.90
                                                Prob > chi2       =    0.0000
One-step results
----------------------------------------------------------------------------------------
                GDPLog |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-----------------------+----------------------------------------------------------------
                GDPLog |
                   L1. |   .9892622   .0505813    19.56   0.000     .8901247      1.0884
                       |
fittedPenFixed_predict |   .0612055   .0297496     2.06   0.040     .0028974     .1195136
          PeakSpeedLog |    .034068   .0065036     5.24   0.000     .0213211     .0468149
            CapitalLog |   -.000042   .0271375    -0.00   0.999    -.0532305     .0531466
              LaborLog |  -.1904744   .1352763    -1.41   0.159    -.4556112     .0746623
                 _cons |   .7450559    1.18921     0.63   0.531    -1.585752     3.075864
----------------------------------------------------------------------------------------
Instruments for differenced equation
        GMM-type: L(2/.).GDPLog
        Standard: D.fittedPenFixed_predict D.PeakSpeedLog D.CapitalLog D.LaborLog
Instruments for level equation
        Standard: _cons
```

Figure 24: Panel data analysis – generalized method of moments

Below, the most significant statistics:

Wald chi2 = 1547.88

Prob > chi2 = 0.000 < 0.001

Table of statistics for each coefficient:

Coefficients	**|z|**	**P>|z|**
Broadband Penetration	2.06 > 1.96	0.040 < 0.05
Peak Speed	5.24 > 1.96	0.000 < 0.05
Capital Stock	0.00 < 1.96	0.999 <> 0.05
Labor Stock	1.41 < 1.96	0.159 > 0.05

The results show that peak speed and broadband penetration have positive effect on GDP and are statistically significant.

6. Conclusion

Broadband has played an important role for the economy, especially in the developed nations. Given the gap that most academic studies on broadband development is devoted to measuring the causality of broadband development in terms of the penetration rate and GDP growth, this study aims to measure the impact of broadband speed on economic growth in the OECD countries.

Contribution on the research of the impact of broadband speed on economic growth

George S. Ford.[1] study quantifies the relationship between higher broadband speeds (10 Mbps versus 25 Mbps) and the growth rates in important economic outcomes in U.S. countries including jobs, personal income, and labor earnings. Doing so exposes the potential for severe selection bias in studies of broadband's economic impact, which is addressed in this study using Coarsened Exact Matching. Once balanced, the data reveal no economic payoff from the 15 Mbps speed difference between the years 2013 and 2015 (when data is available).

Rohman and Bohlin, 2012)[4] study found that the estimated coefficient of broadband speed is statistically significant. Doubling the broadband speed will contribute to 0.3% growth compared with the growth rate in the base year. The results convey that the impact of increasing broadband speed on GDP growth will largely depend on two aspects: (i) the size of the coefficient of the broadband speed (beta) and (ii) the existing economic growth in each country. Consequently, since the coefficient is linear, the impact will also be relatively greater for countries that experienced lower economic growth during previous years.

The findings of this study confirm that broadband adoption affects the economy and that the quality of networks plays a significant role in this process. It is further shown that, for the time period under consideration, the returns from increasing speeds on GDP are positive but diminishing. The upper threshold of speed related gains is moving higher as a result of the “readiness” of the economy (individuals or firms) to make productive use of improved infrastructures through the availability of services that demand more bandwidth. This is an important policy implication when future broadband strategies are considered. The main rationale of this finding rests with standard economic intuition. Every economy consists of a set of resources and skills that determine its economic capacity: on the extensive margin production can only increase if more labor (of identical skills) or capital is put in place. Still, there are various technologies that help the economy produce more by coordinating its activities, reducing communication costs and improving market conditions by increasing its capital- and labor-intensive margins (producing more from a more efficient use of the same resources).

Using this information, policy makers can adapt their strategies on two fronts, namely the effects of wider adoption until saturation and the relative merits of higher quality at various levels of adoption. Moreover, these findings provide the ground for comparison across countries and help plan future investments – with variations in public funding – as the costs and benefits accrue from a measurable impact on GDP.

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