Broadband penetration as an economic growth accelerator

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Abstract: Under the present economic recession, much discussion is made regarding income increase. New technologies and broadband communications in particular can yield comparative advantages in countries. Based on the assumption that income increase is related to broadband penetration, a Granger causality test is applied in 86 countries worldwide. The causality case is tested separately over developed and developing countries, according to their level of broadband penetration. The analysis is aimed to examine the relationship (one-way or bidirectional) between gross national income per capita and broadband penetration level.

Keywords: Granger causality test; broadband services; gross national income; economic growth.

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1 Introduction

Rapid technological progress, liberalisation of telecommunications and regulatory interventions were important growth drivers for information technology and communications. Since the 1980s, the sector of communications has become an integral part of everyday life. The development of mobile telephony, optical networks, satellite systems and the internet introduced, mainly in developed countries, a new way of communication between citizens in modern society. In the late 1990s, broadband brought a further reversal in the traditional communications. The high rate of transmission of information and the stability of the connection gave new impetus to the development of information and communication technologies (ICT). This growth occurs both at the level of software, i.e., new applications are emerging, and in terms of equipment, i.e., the availability of alternatives to access the internet, such as smart phones (smartphones), tablets (pads) and so on.

During the same period a significant economic growth was also recorded in the majority of states. In most developed countries the economic indicators showed a steady upward trend. The developing countries, respectively, albeit with a lag, also followed a path of continuous improvement in their economic situation. ICT developments have accelerated the concept of the global market and provided the means for its consolidation. ICT initially served the rapid exchange of information, while the cost of its use was continuously reduced. Subsequently, technological advances allowed not only for the exchange of information but also for the development of a global market, based on the exchange of products and services.

The end of the 20th century found most countries ready for significant regulatory interventions in the telecommunications industry, one of the most important being the liberalisation of the local loop. The changes facilitated the spread of broadband, which was then in its infancy.

Following the above arguments, the main objective of this study is to analyse the relationship between economic growth and ICT progress, the latter being reflected by the diffusion of broadband technology. For this purpose, a large set of statistical data from 86 countries, worldwide, was used. The countries were divided into two major categories, the developed (45) and developing (41), according to their income level (www.worldbank.org). The statistics cover a wide period of time from the year 1999 up to the year 2011. The analysis is based on the Granger causality test (Granger, 1969), which connects the two parameters examined, i.e., the rate of broadband penetration and the gross national income (GNI) per capita. Through causal analysis the relationship between these two parameters is studied, over the whole dataset (86 countries) as well as over the groups of the developed and the developing countries, in terms of the level of broadband penetration. The relationship can be either unidirectional or bidirectional. The level of diffusion is estimated for each considered country based on the non-symmetric Gompertz model (Rai, 1999). Following the necessary calculations, statistics were split into two groups, corresponding to the points after and before inflection (inflection points – IP). The basic assumption that led to the separation of the data is that the interaction between the two variables, broadband diffusion and GNI per capita does not remain constant over time but rather varies, depending on the level of broadband penetration, which in turn affects the process in a different way.

The rest of the paper is structured as follows: in the next Section 2, a literature review is performed, regarding the links between economic growth and telecommunication development. In Section 3 the methodology used for the evaluation of this work's assumption is presented and analysed. The application of the proposed methodology is performed and presented in Section 4, together with a discussion of the results. Finally, Section 5 concludes.

2 Link between economic growth and telecommunications development

Economic factors, such as income, seem to affect the diffusion of new technologies, as this derives from a number of studies (Loges and Jung, 2001; Distaso et al., 2006; Dwivedi and Lal, 2007). Researchers approach this influence in two ways. Thus, on the one hand they study the effect of income level on the diffusion of ICTs, which is usually described by either gross national product per capita or by GNI per capita. This approach refers to the demand side and it is related to the potential or actual end users of ICTs services. On the other hand, the researchers focus on the impact of the cost of services in the diffusion process, thus covering the supply side of a market (Office of Technology Policy, 2002). However, as broadband penetration increases and technological advances allow the reduction of the cost of services, the effect of income appears to be limited.

Moreover, technological development, mainly during the year 2000, was accompanied by a similar economic growth. In most countries, both developed and developing, the per capita income during the last decade is on the rise (Stern et al., 2004; Hulicki 2008; Whitacre 2008).

According to the aforementioned studies the economic criterion was considered, along with a number of other parameters, such as social and technological, in order to estimate the influence of each parameter over the diffusion process. An alternative approach is the causality analysis, which examines the cross-influence between specific pairs of parameters in detail. The causal relationship is usually studied between economic growth and investments in telecommunication infrastructures. As shown by the results, there is a bidirectional relationship between telecommunication infrastructures and rising income (Cronin et al., 1991). Moreover, it is revealed that the effect of penetration rate of fixed-line telephony on income growth becomes more pronounced when the diffusion of the service increased (Roller and Waverman 2001).

In similar studies, researchers approached the intensity in relationship between telecommunication infrastructures and economic development as well, and apart from the confirmation of a bidirectional relationship, they proved that the intensity of this relationship is not equal in both directions. According to their results, the level of telecommunication infrastructures affects income growth more than the other way round (Dutta 2001; Cieslik and Kaniewsk 2004). Even in recent studies, based on large time series data, the researchers proved that telecommunication investments have a positive influence on income growth (Yoo and Kwak, 2004; Wolde-Rufael, 2007). Telecommunication investments should cause a significant increase in broadband penetration. Conversely, when this goal is not achieved, the impact of telecommunication investments on income may be positive, but not statistically significant. In such cases the unidirectional relationship is usually confirmed, according to which income causes an increase of the diffusion of telecommunication services (Shiu and Lam, 2008).

Among the contemporary, worth mentioning efforts to capture the relation of a country's technology progress with its growth and welfare status is the work of Garbacz and Thompson (2008) focusing on the direct and the indirect economic impact of broadband service penetration using US state-level data. Direct effects are estimated by regressing broadband penetration rates on state GDP per capita, showing little or even a negative impact associated with broadband services. The indirect effect, estimated by the means of a stochastic-frontier production function approach, showed that increasing the broadband network significantly reduces inefficiency in state economies. In Czernich et al. (2009) the effect of broadband infrastructure on economic growth in the panel of OECD countries is examined, by using an annual panel of 25 OECD countries. The approach was based on an instrumental-variable model and a simple growth regression framework, employing a macroeconomic production function with constant returns to scale and three inputs, physical capital, human capital and labour. The evaluation was performed for years 1996–2007 and using traditional voice-telephony and cable-TV networks as proxies for broadband diffusion, providing estimates of the diffusion saturation. A significant positive effect of broadband introduction and penetration on economic growth was found, suggesting that a 10 percentage-point increase in the broadband penetration rate results in a 0.9–1.5 percentage-point increase in annual per-capita growth. Another important contribution is that of Gruber and Koutroumpis (2011), who assessed the impact of mobile telecommunications on economic growth, by employing a simultaneous equation model and using annual data from 192 countries over the period 1990–2007. The model was composed of an aggregate production function which expressed GDP in terms of production factors in each country and each year considered. These factors were capital, labour and the stock of mobile and fixed telecommunications infrastructure. The main findings showed that mobile telecommunications diffusion significantly affects both GDP growth and productivity growth. However, this impact turned out to be smaller for countries with a low mobile penetration, which are usually low income countries. The contribution of mobile telecommunications to annual GDP growth was found as 0.11% for low level countries, while for high income countries it was found as high as 0.20%.

The International Telecommunications Union was also concerned with the impact of broadband on the economy (Katz, 2012), by studying of the impact of broadband on economic growth, productivity and job creation, focusing on OECD countries and the USA. It covered a wide range of years, from 1980 to 2007 and numerous aspects including broadband aggregate impact on GDP growth, the differential impact of broadband by industrial sector, the increase of exports, as well as changes in intermediate demand and import substitution. The positive contribution of broadband to GDP growth was confirmed, but the results turned out to vary substantially among the considered countries. According to the reported results, a 10% increase in broadband penetration yields an increase in GDP by a proportion ranging from 0.9% to 3.6%. As far as the impact of broadband on job creation is concerned, a creation of a substantial number of jobs per year was recorded, both direct and indirect, ranging from some 140,000 to 200,000, for the considered countries. More recently, Katz and Koutroumpis (2013) measured cross-country digitisation progress by constructing an index, using a number of elements and indicators as proxies of digitisation metrics. They included, among others, fixed and mobile penetrations and fees, 3G penetration, internet bandwidth and broadband speeds, GDP, e-government maturity, etc. The sample consisted of 150 countries, spanning from years 2004 to 2010, and the impact of digitisation on economic growth was evaluated by the use of an endogenous growth model linking GDP to the fixed stock of capital, labour force and the digitisation index as a proxy of technology progress. The results suggested that a 10 point increase in the index has approximately a 3% impact on GDP, resulting in an annualised effect of 0.50%, deriving some important public policy implications, regarding the formulation of ICT policies. In addition, this work provided recommendations and policy implications, and introduced a methodology or the calculation of the investment required to achieve full broadband penetration.

According to the literature, the economic growth was accompanied by the development of ICTs and the increasing penetration rate of telecommunication services. In addition, the development of telecommunications seems to be affected and determined by the general environment, as described by the living, educational and social level. In this study, the grouping of countries into developed and developing aims to confirm the relationship between income and telecoms, the latter expressed by the penetration of broadband technology. Furthermore, the clustering of countries, according to their broadband penetration level could also assess the behaviour of the causal relationship with respect to time. This clustering is achieved by considering a critical point in the process of diffusion, i.e., the inflection point, which in turn affects the diffusion shape and the maximum level of penetration (saturation).

3 Methodology

The study of causal relationship between variables is a matter of study for a broad range of researches aiming to determine whether one time series is useful in forecasting another. The importance of these studies becomes higher if variables come from different scientific fields, such as social and economic sciences. Among the methodologies developed towards this direction is the Granger causality (Granger 1969), which was introduced in 1969 and is based on a hypothesis test for measuring the ability of predicting the future values of a time series using past values of another one. According to Granger, the causality relationship is based on two principles:

- the cause happens prior to its effect
- the cause has unique information about the future values of its effect.

The Granger methodology was used in a number of studies across a number of fields. Among the most recent works is Beyzatlar et al. (2014), investigating the relationship between income and transportation of EU-15 countries using a panel dataset covering the period 1970–2008 (Tiwari, 2014), where the Granger-causality between variants of the energy consumption sources and GDP for the USA was examined, and Puente-Ajovín and Sanso-Navarro (2015) who analysed the causality between debt and growth across OECD countries.

According to the Granger causality, a variable A 'Granger-causes' (or 'G-causes') a variable B, if variable B can be better predicted using the histories of both A and B, then it can be predicted using the history of B alone. This holds if the expectation of B given the history of A is different from the unconditional expectation of B.

$$E(B \mid B_{t-k}, A_{t-k}) \neq E(B \mid B_{t-k}) \quad (1)$$

Its mathematical formulation is based on linear regression modelling of stochastic processes. The statistical validation of the Granger causality test is made by using the statistical *F* (*F*-statistic). The steps followed to implement a hypothesis test are as follows:

- setting of the null hypothesis
- estimation of the *F*-statistic
- definition of the decision rule.

The procedure for the Granger causality test involves the estimation of two separate equations. In each of these equations, the present value of a variable (A_t or B_t) is a function of the same in a previous time (A_{t-N} or B_{t-N}), i.e., lagged values, and the other variable (B_{t-N} or A_{t-N}). The number of possible lags depends on the data chosen by the researcher and, therefore, the Granger causality test requires time series data (Wooldridge, 2002; Gujarati, 2004). Following the reasoning that the previous values of parameter A significantly affect the values of parameter B, it can, therefore, be considered that A influences B. The mathematical formulation of this reasoning is described by equations (2) and (3):

$$A_t = a_0 + \sum_{i=1}^{N} a_i \times A_{t-i} + \sum_{i=1}^{N} b_i \times B_{t-i} + e_t \quad (2)$$

$$B_t = c_0 + \sum_{i=1}^{N} c_i \times A_{t-i} + \sum_{i=1}^{N} d_i \times B_{t-i} + v_t \qquad (3)$$

where N is the range of lagged values, i is any lag and e_t and v_t refer to the errors of the equations. The first equation is used to control the null hypothesis (H_0), according to which B does not cause changes in A. The study of this case is made through two equations, with and without constraints, i.e., restricted and unrestricted regression, respectively. Similarly, the study of equation (3) involves the estimation of the corresponding restricted and unrestricted regressions, where according to H_0 A does not cause changes in B.

Based on equations (2) and (3) the F statistic can be calculated, which in turn would lead to the rejection of the null hypothesis if it exceeds the acceptance threshold. The calculation of the F statistic is as follows:

$$F = \frac{(\text{RSS}_r - \text{RSS}_{un}) / \rho}{\text{RSS}_{un}(T - 2\rho - 1)} \qquad (4)$$

In equation (4) RSS_r is the sum of squares of the residuals regression equation with restrictions, while RSS_{un} is the respective sum of squares of the residuals of the equation without restrictions, ρ is the range of lags (lag length) and T is the number of observations. The suitable range of lags which should be taken into account in the model is decided according to the Akaike information criterion (AIC) (Akaike, 1974). The proper lag length is the one with the lowest value of AIC. It should be noted that these calculations refer to the equations without restrictions.

Table 1 contains the decision rule, which will be applied over the results, in order to reveal the kind of the relationship.

Table 1 Results based on the definition of the decision rule

	Reject H_0	*Accept H_0*
Reject H_0	Bidirectional relationship	A causes changes to B
Accept H_0	B causes changes to A	There is no relationship

4 Granger causality test cases and results

As mentioned earlier, the data used for evaluation were collected from the World Bank (www.worldbank.org) for 86 countries, on an annual basis. They describe broadband maturity and economic status, as expressed by penetration and the GNI per capita, respectively. Apart from the whole dataset, two groups were furthermore considered, the 45 developed and 41 developing countries. The criterion used for this clustering is the GNI per capita. According to statistics derived from the World Bank, countries are separated by income into four categories. These categories, with respect to the income level, are high, upper-middle, lower-middle and low. The developed countries are those where GNI per capita belongs to the first category (high income). Countries corresponding to upper-middle, lower-middle and low income levels are addressed as the developing countries. The dataset used consists of time-series data, across all the considered countries, on an annual basis, starting from year 1999 up to 2011. In a next step of the study, each one of the two datasets was further split into two other datasets according to their broadband diffusion maturity.

The two variables involved in the control of the Granger causal relationship are the proportion of broadband connections and GNI per capita. Table 2 shows the countries according to their level of development, the latter reflected by income per capita.

Table 2 List of developed and developing countries

Developed countries (*45*)				
Norway	Belgium	Macao, China	Israel	Saudi Arabia
Luxemburg	Australia	UK	Greece	Bahrain
Switzerland	Canada	Italy	Slovenia	Czech Republic
Denmark	Germany	Hong Kong	French Polynesia	Slovakia
Sweden	UAE	Island	Portugal	Trinidad and Tobago
Netherlands	France	Spain	Bahamas	Esthonia
Finland	Japan	Cyprus	Korea	Croatia
USA	Ireland	Brunei Darussalam	Malta	Hungary
Austria	Singapore	New Zeeland	Oman	Poland
Developing countries (*41*)				
Latvia	Lebanon	St. Lucia	Peru	El Salvador
Venezuela	Argentina	St. Vincent and the Grenadines	FYROM	Cape Verde
Lithuania	Romany	Bulgaria	Algeria	Georgia
Uruguay	Malaysia	Belarus	Jordan	Moldavia
Chile	Mauritius	Maldives	China	Viet Nam
Russia	Kazakhstan	Serbia	Tunisia	Mexico
Turkey	Panama	Colombia	Thailand	Montenegro
Brazil	Grenada	Dominican Republic	Albania	Jamaica
Beliz				

Before conducting the analysis, it should be ensured that variables are stationary, as time series data pose risks to the reliability of the results. Therefore, and in order to remove any possible autocorrelation effects, a dataset transformation was performed, based on the generalised differences (Hanke and Wichern, 2009). In addition, the Durbin–Watson index was calculated, showing that there was no indication of positive or negative autocorrelation.

The current analysis was performed in three stages. Initially, the Granger causality test was applied over the whole dataset of developed and developing countries. Since broadband diffusion maturity, as expressed by the corresponding penetration rates and diffusion levels, differs significantly among developed and developing countries, each case was considered separately. It was divided in two sub-sets based on the maturity level of broadband diffusion, as expressed by the inflection point (IP) of the diffusion. The IP in a diffusion process corresponds to the point where its maximum rate is met, starting to decline after that, until the diffusion process reaches its maximum level, the saturation level. The IP is crucial in determining the saturation point (Bewley and Griffiths, 2003; Lee et al., 2011) and, therefore, is considered a sufficient proxy to describe the maturity of the broadband diffusion process. Based on their formulation and in terms of their IP, diffusion models are characterised as symmetric if they reach their maximum rate at the 50% of the diffusion process, or asymmetric otherwise. The evaluation process, in the context of this work, is based on the non-symmetric Gompertz model, according to which the IP of each country is met at about the 37% of the calculated saturation level, i.e., the maximum estimated penetration level of broadband services.

The majority of developed countries reached the IP in the year 2004, and, therefore, the lag length for this case was seven, from 2004 up to 2011. Similarly, the lag length for developing countries was six, from 2005 up to 2011, as these countries lagged behind regarding broadband penetration. In this way, despite the whole dataset, two additional sub-sets were examined, in both developed and developing countries, i.e., before and after IP. It should be noted that the results obtained by calculating the IP for the two categories of countries differ observably. For example, in Denmark the saturation point for broadband penetration was estimated to be over 40%, while in Brazil it was 15%. The results from the Granger causality test for developed countries are presented in Table 3.

Table 3 Granger causality test results for developed countries

		F-statistic	*Durbin-Watson*	H_0
Whole dataset	H_1: Broadband penetration does not cause GNI per capita	0.98	1.824	Accept
	H_2: GNI per capita does not cause broadband penetration	4.11**	2.125	Reject
After IP	H_1: Broadband penetration does not cause GNI per capita	2.70*	1.885	Reject
	H_2: GNI per capita does not cause broadband penetration	0.13	1.896	Accept
Before IP	H_1: Broadband penetration does not cause GNI per capita	0.20	2.32	Accept
	H_2: GNI per capita does not cause broadband penetration	5.11**	2.078	Reject

*$p < 0.05$; **$p < 0.01$.

According to the findings, the Granger causality test in developed countries revealed different results depending on each case. Regarding the evaluation over the ‘whole dataset’, the hypothesis that broadband penetration affects income is rejected. On the contrary, it seems that GNI per capita can affect broadband penetration positively. These results are similar to those reached regarding the ‘before IP’ dataset.

However, the Granger causality test over the ‘after IP’ groups provided different results. More specifically, there is a causal relationship between income and broadband, as broadband penetration can cause positive changes to GNI per capita. Indeed, GNI per capita is higher in the group of 'after IP' broadband penetration level countries, as compared to the group of 'before IP' countries. The determination of the appropriate lag length was based on AIC. In the case of the whole dataset, the lag length with minimum AIC was equal to the whole number of past time periods, i.e., lag = 11. Regarding the lag lengths, for the H1 hypothesis this was estimated as equal to five (lag = 5), while for the H2 the appropriate lag length for the 'after IP' dataset was equal to one (lag = 1). In the 'before IP' case, the appropriate lag length was estimated to be equal to two (lag = 2) in both H_1 and H_2. Results from developing countries are depicted in Table 4.

The group of the developing countries provided results similar to those regarding the developed countries in the 'after IP' and 'before IP' cases. It seems that broadband penetration affects positively GNI per capita after the inflection point is met, however the vice versa is not true. In addition, GNI per capita can cause a growth in broadband penetration in the 'before IP' case, while income seems to be unaffected by broadband diffusion level. Finally, a bidirectional relationship is revealed for the 'whole dataset-case, between the two variables, since both broadband penetration and GNI per capita interact positively with each other (positive F-statistic values). It can be accordingly concluded that the Granger causality test can lead to different results, depending on the timing of the evolution of a process. The appropriateness of the time lag for the whole dataset was calculated at the seventh lag (lag = 7) for H_1 and at the fifth (lag = 5) for H_2. For the 'after IP' case, the appropriate lag length was equal to three (lag = 3) for H_1 and equal to one (lag = 1) for H_2. In the 'before IP dataset' H_1 was tested in the first lag (lag = 1), while H_2 was tested in the fifth lag (lag = 5).

Table 4 Granger causality test results for developing countries

		F-statistic	*Durbin-Watson*	H_0
Whole dataset	H_1: Broadband penetration does not cause GNI per capita	2.76*	1.523	Reject
	H_2: GNI per capita does not cause broadband penetration	3.31*	1.577	Reject
After IP	H_1: Broadband penetration does not cause GNI per capita	4.34**	2.145	Reject
	H_2: GNI per capita does not cause broadband penetration	1.53	1.463	Accept
Before IP	H_1: Broadband penetration does not cause GNI per capita	0.19	2.074	Accept
	H_2: GNI per capita does not cause broadband penetration	3.65**	2.052	Reject

*$p < 0.05$; **$p < 0.01$.

5 Conclusions

In this analysis, the relationship between broadband diffusion and GNI per capita is examined. The aim of the analysis is to provide information regarding the interaction of these two variables. To do this, a Granger causality test is applied over a number of countries, which were divided into two groups, the developed and the developing. The criterion used for the separation was GNI per capita, based on the classification used by the World Bank. The main assumption of this analysis lies on the hypothesis that the relationship between income and broadband diffusion differs, depending on the level of the later variable. Therefore, each dataset, i.e., the 45 developed and 41 developing countries, was examined separately, considering the level of broadband diffusion, as expressed by the inflection point (IP), in order to create the two clusters of countries, i.e., 'before IP' and 'after IP'. The estimation of IP of each country was based on the non-symmetric Gompertz diffusion model. For comparison reasons, the Granger causality test was also applied over the whole dataset.

According to the results derived from developed countries, it seems that in the 'after IP' case, broadband penetration causes positive changes in income, while in the 'before IP' case, income will precede positive changes in broadband diffusion. Though it seems that countries can have economic benefits if they enhance broadband diffusion. On the contrary, countries with low broadband penetration, i.e., 'before IP', should focus their efforts on the provision of economic incentives in order to boost broadband demand. It is worth mentioning that results for all the developed countries are similar to those of the 'before IP'.

Moreover and regarding the developing countries, results reveal that a one-way relationship exists between the broadband diffusion and economic growth. More specifically, in the 'after IP' case, broadband diffusion can be considered as an accelerator for income increase, while the opposite relationship holds in the 'before IP' case. As far as the results for all the developing countries are concerned, a bidirectional relationship is estimated between GNI per capita and broadband penetration. Results verify the importance of examining the different cases according the diffusion level, since an analysis over the data as a whole (single group) would probably derive misleading findings.

Findings of this work provide corresponding policy directions, indicating that there is a need to insert broadband diffusion support within the larger ICT context provided by digital agendas, while focusing on country and region-specific particularities according to the local socio-economic and demographic conditions. Despite that broadband diffusion does not demonstrate positive impact on economic growth in all cases, true economic growth is very likely to be eventually met. Furthermore, the relationship between broadband and employment should be carefully explored, as it may result to mechanisms for development.

In terms of future research directions in the context of the present work, a more disaggregated dataset may provide many answers and suggestions as to where broadband may be more effective as a policy tool, since it would reveal the specific characteristics of regions or countries.

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