Regional inequalities in the impact of broadband on productivity: Evidence from Brazil

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Abstract

The aim of this paper is to perform an analysis of the impact of broadband on regional productivity in Brazil. The possibility of performing a regional approach, instead of the usual country-level analysis, constitutes an opportunity to decode the economic impact of broadband at territories which share a common institutional and regulatory framework as are the regions inside a same country. The main focus of this paper is to find out if the economic impact of broadband is uniform across all territories of the country. Results suggest that the impact of broadband on productivity is not uniform across regions, and seems to be yielding higher productivity gains for less developed regions, a result which is robust after controlling for differences in quality, network effects, human capital, sectorial composition, urbanism and the age of the workforce. Another important result verified in this paper is that faster download speed and critical mass to account for network externalities enhance of the economic impact of broadband. The fact that most underdeveloped regions in Brazil seem to be benefiting more from broadband may suggest that broadband can constitute a factor favoring regional cohesion in Brazil, although further research will be needed to confirm that asseveration.

JEL Classification: O33, O47, R11

Keywords: Broadband, Information and Communication Technologies, Regional Productivity

1. Introduction

Information and Communication Technologies (ICT) in general, and broadband in particular, have been extensively studied in the economic literature as a potential source to increase employment and generate economic growth. There are, however, some gaps among the literature that remain unfilled and that have motivated the present research.

In first place, while the bulk of the literature has focused its analysis either at country-aggregate or firm levels, evidence of subnational-regional analysis of broadband impact on local productivity is still scarce, and mainly referred to the United States.

In second place, those empirical studies that have addressed the regional level usually have replicated the analysis performed at cross-national level, not focusing its approach's on a regional perspective. For regional analysis it is key to understand if broadband is able to produce a uniform impact on productivity across the regions of a country. In that sense, if the impact of broadband on productivity is found to differ territorially inside a country, then the analysis will have to contemplate the regional dimension, intending to find out why some regions are able to extract more productivity spillovers from technology in comparison with others. The impact of broadband on productivity may depend on a variety of regional attributes, such as sectorial structure, demography, human capital, level of development, among others.

The possibility of working at a regional level provides some advantages. Country-level analysis is usually affected by important heterogeneities across countries in terms of institutions, culture, regulations, etc. In contrast, regional analysis provides a more homogeneous framework which allows filtering for those potential heterogeneities and as a result it may help to find a more accurate measure of the impact of broadband on productivity.

To find out if there are differences in the regional productivity impact of broadband, additional factors will be considered as potential enablers, like connection quality and critical mass externalities. The possibility of getting homogeneous data on download speeds provides the possibility of considering quality differentials among regions. A question that motived this approach was to find out if continuous improvements in speed levels of current connections should also constitute a priority for operators and policy-makers, along with universalization.

The empirical analysis will focus in Brazil, which is an emerging country which has reached important economic growth over the last decades. A recent report by CEBR[1] forecasted that Brazil will become the world's fifth largest economy in 2023, overtaking UK and Germany. The last few years it has reduced significantly the levels of poverty, after combining social policies with economic growth. As a result of its potentiality, Brazil has been classified as one of the BRICs (the others being Russia, India and China). A key of this process was the openness of its economy for foreign investment since the nineties where many state industries were privatized. The presence of Brazilians multinationals in the world has grown considerably, as well. Its entrance onto the world stage has been reinforced by the high profile international events that will be hosted in the country: the football World Cup in 2014, and the Olympic Games 2016 at Rio de Janeiro.

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[1] Centre for Economics and Business Research

Considering the importance of broadband as an essential infrastructure, the Federal Government of Brazil has launched the "Programa Nacional de Banda Larga", with the objective of extending the provision of broadband, especially in regions which are lacking connectivity. The plan, launched at mid-2010, has a target of reaching 40 million of households connected for 2014, and is acting on several fronts, such as expansion of optic fiber networks, and tariff reduction programs, including the implementation of a "popular broadband" tariff for connections of 1 mbps per 35 reais per month[2]. As the chosen cities for the first phase of the plan had not been attended till mid-2011, the incidence of the plan will remain out of reach of the scope of this paper. Despite not being considered in the analysis, the present paper may bring out some inputs to estimate its future economic impact across the states.

This paper is structured as follows: section 2 will resume a review of recent literature on ICT and broadband economic impact; section 3 will present a theoretical model that will constitute the basis for the econometric analysis; section 4 will expose a descriptive analysis of the available data; section 5 will present the main results and discussion; and finally section 6 will briefly conclude with some remarks and policy discussion.

2. Literature review

Economic impact of infrastructures has been widely studied in the economic growth literature, following the initial contribution of Aschauer (1989), who included public capital as a productivity determinant. The impact of telecommunications infrastructure has also been studied, being Roller and Waverman (2001) one important contribution in this sense.

The diversity of channels through which ICT can contribute to productivity and economic growth have been extensively studied in the literature. At a firm-level, ICT can contribute to reduce communication costs (Jorgenson, 2002), allowing a quicker processing of information and lowering coordination costs, the quantity of supervisors required (reducing labor costs), and facilitating the process of decision taking (Cardona et al, 2013; Arvanitis y Loukis, 2009; Atrostic et al, 2004; Gilchrist et al, 2001). ICT may promote substantial restructuring (Brynjolfsson y Hitt, 2000). As a result, internal process may become more flexible and rational, reducing capital requirements through improving equipment utilization and inventory reduction. Through intangible organizational capital accumulation, ICT may produce externalities prompting improved efficiencies in production process (Stiroh, 2002). One important source of productivity is innovation, and ICT has been widely seen as a special case of technologies that enables further innovations and enhances its diffusion. The possibility of improving communication channels with suppliers, clients and other firms may facilitate the adoption of new technology, prompting knowledge spillovers across firms and regions (Czernich et al, 2011). The increased speed of communication and information flows may also improve access to markets and enhance competition. As a result of all those attributes, ICT has become a substantial part of the social and business environment (Cardona et al, 2013), allowing to increase total factor productivity in industries that are intensive in ICT utilization.

[2] Source: Ministério das Comunicações

In the last few years most of ICT-derived contribution to productivity has come from the development of broadband high-speed internet connections. Ford et al (2008) had even stated that the diffusion of broadband constitutes the most significant telecom policy challenge of the last thirty years. Broadband has been classified as a General Purpose Technology (GPT) by some authors (Mack and Faggian, 2013; Czernich et al, 2011). Its characteristics as a GPT make broadband a technology that may change how and where economic activity is organized (Harris, 1998; Helpman and Trajtenberg, 1998). Broadband may constitute a special technology with a different impact on growth in comparison with other technologies (Czernich et al, 2011).

Because of its attributes, some authors had stated that the new technologies influence productivity beyond the effect of regular capital goods. According to Mack and Faggian (2013), and Jordan and Leon (2011), broadband now constitutes a key part of the necessary infrastructure for development, in the same way as previous advances such as railroads, roads and electricity.

Broadband networks provide high speed internet access to a very diverse multimedia services, such as video streaming, tele-working, online education and training, e-Government and e-Health, (Koutroumpis, 2009; Suriñach et al, 2007), providing wealthier information and reducing search and transaction times. While the telecommunications industry is primarily affected by the infrastructure deployment, broadband spillovers result in externalities in other sectors of the economy (Koutroumpis, 2009).

Broadband infrastructure allows the generation and diffusion of decentralized information in markets for which information is an input, fostering competition and development of new products processes and business models (Czernich et al, 2011). Distribution of ideas and information are a key driver of economic growth according to theories of endogenous growth (Lucas, 1988; Romer, 1990; Aghion et al, 1998). Cheaper information dissemination can facilitate the adoption of new technologies devised by others, as well as constitute an innovation enabler. Qiang et al (2009) even argue that broadband may improve human capital, as individuals can acquire skills and develop social networks through web applications. Additionally, individuals can seek better prices, and improve job search through internet connections. Internet and communication technologies lower the fixed cost of acquiring information and the variable costs of participating in markets (Norton, 1992; Leff, 1984).

Recent empirical analysis has mainly concentrated on analyzing the broadband impact on economic growth. Czernich et al (2011) studied a simple of 25 OECD countries for period 1996-2007 and found that a 10% of increase in broadband penetration contributes to 0.9-1.5 percent of GDP per capita. Koutroumpis (2009) studied a simple of 22 OECD countries for period 2002-2007, finding that a 10% increase in broadband penetration contributed to 0.25% in GDP growth. Qiang et al (2009) found that a 10% increase in broadband penetration contributed to more than 1% of increase in per capita GDP growth.

At a regional level, research has been much scarcer, and mostly referred to United States. For instance, Crandall et al (2009) studied the effects of broadband deployment on output and employment in US states for 2003-2005 periods. They find a positive association of employment and broadband use in several industries, and a positive but not significant association between output and broadband. Mack and Faggian (2013) analyzed the regional impact of broadband provision for US counties, finding that it had a positive impact on productivity only when accompanied with high skills. Lehr et al (2005) studied the impact of broadband at US communities, finding out a positive impact of broadband on economic growth.

An ongoing debate in the literature is related to the link between the new technologies and underdeveloped regions. It is believed that ICT may open possibilities to isolated regions to overcome traditional disadvantages deriving from remoteness location. As a result, new technologies and the diffusion of internet may reduce the role played by agglomerations. Some authors had even talked about the "death of distance" as a result of an eventual widespread deployment of ICT services (Cairncross, 2001). According to this view, distance will be less important and peripheral regions would benefit from opportunities that were not available before (Negroponte, 1995; Kelly, 1998; Quah, 2000; Bonaccorsi et al, 2005).

In some cases, the presence of broadband infrastructure allows the development of poor regions, enhancing some degree of territorial equilibrium (Suriñach et al, 2007). Isolated regions may present some advantages as lower wages and property costs, which can be fully exploited if good broadband infrastructure is available. In that case, it can attract the localization of companies which may be suffering from congestion costs in more developed regions, increasing demand and activity in isolated regions. This may produce a positive spiral of increased activity that may help even people who is not a user of broadband.

Even if not related to regional analysis, Thompson and Garbacz (2011) found that broadband had a relatively more favorable economic impact in lower income countries than in high income countries. Qiang et al (2009) found that the growth effects of broadband, as well as those of other technologies, were higher in low income countries than in high income economies. Fernández-Ardèvol et al (2011) find out that the economic impact of mobile phones was larger in Latin America than in OECD countries.

Although not considering broadband, Barrios et al (2008) found out that ICT investments have contributed significantly to regional convergence in Spain. They also stated that the development of ICT activities constitute a potentially good candidate for promoting regional development. Basant et al (2006) found that the rate of return of ICT investment seemed to be much larger in emerging countries like Brazil and India than in more developed countries. In the same line, Ding et al (2008) have found that telecommunication infrastructure contributed significantly to regional convergence in China, supporting investment policies in telecommunications in lagging regions of developing countries. They state that facilitating telecommunications infrastructure is important for assisting economic growth in the less developed regions of developing countries with poorly developed telecom infrastructure.

On the other hand, other authors argue that the economic impact should be bigger in high income economies. For instance, Katz (2012) stated, for a country-level analysis that economies with lower broadband penetration tend to exhibit a lesser contribution of broadband to economic growth. The reason for this statement is linked to network externalities resulting from greater broadband penetration. This critical mass effect may lead to increasing returns for broadband penetration. Other authors stated that ICT may exacerbate disparities between regions, both inside and across countries, because regions may differ not only in ICT endowment, but also in the possibilities to make a productive use of it (Gareis and Osimo, 2004). Billón et al (2009) argued that agglomerations and internet may be complementary instead of substitutes. Bonaccorsi et al

(2005) stated that disparities and inequalities seemed to be reinforced, rather than reduced, by ICT diffusion. Along with that, the importance of complementarities (i.e.: human capital), sectorial composition and institutional framework may contribute to a higher economic impact in more developed economies. At the same time, the referred decrease of the role of distance as a result of the new technologies may be over-optimistic, as only codified knowledge can be transmitted through ICT, meaning that for tacit knowledge diffusion distance will remain to be relevant.

A relatively unstudied angle of broadband impact is that related to differences in its quality (downloading speed). A recent paper by Rohman and Bohlin (2013) has found out for a sample of 34 OECD countries during the period 2008-2010 that doubling the broadband speed contributes to 0.3% growth compared with the growth rate in a base year. This is because low transmission capacity and speed of dial-up internet severely limit access to content-dense applications. Howell and Grimes (2010) argue that fast internet access is considered a productivity-enhancing factor. As a result, quality of connections should also be considered as a potential factor which may contribute to regional differences in the economic impact of broadband.

All the previous arguments may give an insight that the impact of broadband on productivity may be very different across regions, even inside the same country. The possibility of performing the analysis in a big country as Brazil, which exhibits important regional inequalities, may provide a better understanding of the regional dimension of the impact of broadband in productivity, and may contribute to evaluate its suitability as an instrument for regional cohesion.

3. Theoretical Model and empirical specification

In this section a theoretical model will be presented, in which economies are supposed to produce according to a Cobb-Douglas production function with various input factors:

$$Y_{it} = A_{it} K_{it}^{\alpha} L_{it}^{\beta} H_{it}^{\gamma} \qquad [1]$$

Where Y represents output, K is physical capital stock, L is labor and H denotes human capital, approximated as $H = e^{h}$, where h reflects the efficiency of a unit of labor, in a similar fashion as Hall and Jones (1999). Subscripts i and t denote respectively regions and time period. The term A represents Total Factor Productivity (TFP), which reflects differences in production efficiency across regions. TFP can be expressed as:

$$A_{it} = \Omega_i(X)\, BB_{it}^{\Phi} \qquad [2]$$

TFP is stipulated to depend on some region-specific characteristics, represented by $\Omega_i(X)$, a term which is influenced either by a vector of control variables X and by time invariant idiosyncratic productivity effects, which may make some regions more productive *per se* because of unobserved heterogeneity. As it is supposed that broadband may contribute to increase productivity, and to facilitate the development of new products and process and the adoption of new technologies devised by others, A is assumed to depend positively on the level broadband infrastructure denoted by BB. The stock of broadband infrastructure is used, instead of investment, because users demand infrastructure and not investment *per se* (Koutroumpis, 2009). An expected positive value for Φ may suggest the productivity gains derived from broadband.

The empirical specification will be derived omitting the subscripts for region and time period for the sake of simplicity. The lack of available data for state-level physical capital stocks in Brazil will require of some assumptions and rearrangements to derive the empirical specification. Following economic theory, if markets are competitive, capital earns its marginal product (Romer, 2006). As a result, firms in this economy will acquire physical capital until its marginal productivity equals its price, usually approximated by the real interest rate r:

$$\frac{\partial Y}{\partial K} = A\alpha K^{\alpha-1} L^{\beta} H^{\gamma} = r$$

From this expression, the demand for physical capital can be derived and expressed as:

$$K = \left[\frac{\alpha A L^{\beta} H^{\gamma}}{r}\right]^{\frac{1}{1-\alpha}}$$

Inserting the derived demand for physical capital in [1], yields an expression for output which do not depends on physical capital on the right side:

$$Y = A\left[\frac{\alpha A L^{\beta} H^{\gamma}}{r}\right]^{\frac{\alpha}{1-\alpha}} L^{\beta} H^{\gamma}$$

Performing some further operations, output can be expressed as:

$$Y = \frac{\alpha^{\left[\frac{\alpha}{1-\alpha}\right]} A^{\left[\frac{1}{1-\alpha}\right]} L^{\beta\left[\frac{1}{1-\alpha}\right]} H^{\gamma\left[\frac{1}{1-\alpha}\right]}}{r^{\left[\frac{\alpha}{1-\alpha}\right]}}$$

Under the assumption of constant returns to scale for physical capital and labor, the following equality can be expressed: $\alpha + \beta = 1$. Then:

$$Y = \frac{\alpha^{\left[\frac{\alpha}{1-\alpha}\right]} A^{\left[\frac{1}{1-\alpha}\right]}\, L\, H^{\gamma\left[\frac{1}{1-\alpha}\right]}}{r^{\left[\frac{\alpha}{1-\alpha}\right]}}$$

The previous expression can be easily manipulated to obtain a measure of labor productivity which do not depends on the stock of physical capital:

$$\frac{Y}{L} = \frac{\alpha^{\left[\frac{\alpha}{1-\alpha}\right]} A^{\left[\frac{1}{1-\alpha}\right]}\, H^{\gamma\left[\frac{1}{1-\alpha}\right]}}{r^{\left[\frac{\alpha}{1-\alpha}\right]}}$$

Introducing [2], this yields:

$$\frac{Y}{L} = \frac{\alpha^{\left[\frac{\alpha}{1-\alpha}\right]} \left[\Omega(X) B B^{\Phi}\right]^{\left[\frac{1}{1-\alpha}\right]}\, H^{\gamma\left[\frac{1}{1-\alpha}\right]}}{r^{\left[\frac{\alpha}{1-\alpha}\right]}}$$

This can be linearized by applying logarithms:

$$\ln\left[\frac{Y}{L}\right] = \left[\frac{1}{1-\alpha}\right]\ln\alpha + \left[\frac{1}{1-\alpha}\right]\ln\Omega(X) + \left[\frac{1}{1-\alpha}\right]\Phi\ln BB + \left[\frac{1}{1-\alpha}\right]\gamma h - \left[\frac{\alpha}{1-\alpha}\right]\ln r$$

The interest rate is the same across the states, because financial markets are integrated inside the country, and as the long-term rate is supposed to vary little over the time period analyzed, it will be assumed as constant. Renaming the constant factor $\Gamma_0 = \left[\frac{1}{1-\alpha}\right] \ln \alpha - \left[\frac{\alpha}{1-\alpha}\right] \ln r$, and the following parameters successively as Γ_i then the empirical specification is:

$$\ln\left[\frac{Y}{L}\right] = \Gamma_0 + \Gamma_1 \ln \Omega(X) + \Gamma_2 \ln BB + \Gamma_3 h \qquad [3]$$

As a result, the empirical specification will relate labor productivity on the left-side to some right-side variables: human capital, broadband penetration and some controls. The parameter α cannot be identified through the empirical specification, so the physical capital share on the income obtained by the Brazilian national accounts will be used to recover the structural parameters: $\Phi = \Gamma_2\ (1-\alpha)$ and $\gamma = \Gamma_3\ (1-\alpha)$.

The previous specification may be useful to obtain a common-regional measure of the impact of broadband on productivity, but is inappropriate to account for differences of impact across regions. As a result, further strategies will require of slight modifications to the TFP term expressed in [2]. As stated in the literature review, broadband may have a different impact depending on the degree of development of the region. Additionally, that economic impact of broadband may vary depending on the quality of the connection, and because of the presence of network externalities in the case of connectivity reaching some threshold. As a result of all that, [2] can also be expressed as:

$$A = \Omega(X)\ BB^{(\Phi + \Phi_{LP} LP + \Phi_{MP} MP + \delta Quality + \lambda Mass)} \qquad [2']$$

Where LP and MP represent respectively dummy variables associated to the level of development of the region: Low Productivity and Medium Productivity. As a result, the base scenario will constitute the impact of broadband on high productive regions. The term $Quality$ reflect broadband quality, and $Mass$ represents a dummy variable which takes the value of one if the region has reached a threshold of penetration. The election of quality and critical mass reflect that the incidence of these variables is intrinsically linked to interaction with broadband. Other possible variables, such as human capital and sectorial composition will be added among controls X and will not be measured as exponents in BB, as may probably have a direct incidence in TFP.

The interpretation of the parameters associated to broadband provides some of the contributions of the model. For instance, if $\Phi_{LP} = \Phi_{MP} = 0$, then the impact of broadband on productivity can be considered as uniform across regions. On the contrary, if $\Phi_{LP} \neq 0$, or $\Phi_{MP} \neq 0$, then research should focus in finding out why some regions appear to be extracting more productivity gains from broadband than others. If $\delta > 0$ then a higher quality produces an additional impact on productivity in comparison with the mere disposal of broadband. On the contrary, if $\delta = 0$ then quality does not matter for productivity, and in that case universalization will remain the main priority instead of the improvement of current networks. Additionally, if $\lambda > 0$ then network externalities are present, and as a result in those regions were broadband penetration reach a specific threshold, the economic impact will be bigger.

The procedure to derive the empirical specification and the strategy for recovering structural parameters are similar to that exposed by the base model.

4. Data and Exploratory Analysis

Table 1 resumes the description of the variables to be used in the empirical analysis. Output will be measured through Gross Value Added, which subtracts intermediate inputs from the gross output, usually considered a more accurate measure of the actual surplus created (Cardona et al, 2013). The data, extracted from the IBGE database[3], has been deflated to 2000 constant prices.

Table 1
Variables for empirical analysis

Variable	Description	Source
Productivity	Gross Value Added per worker in Reais at 2000 constant prices	IBGE
Broadband	Number of subscriptions (>512kbps) per 100 inhabitants	Telebrasil
Literacy rate	Literacy rate of population over 15 years old	IPEA
Speed	Weighted average in mbps	Computed from data of Telebrasil
Agriculture	Percentage of sectorial GVA	IBGE
Services	Percentage of sectorial GVA	IBGE
Urbanism	Percentage of people living on urban areas	IPEA
Youth workforce	Percentage of working-age population under 29 years old	IBGE

Considering the importance of ICT to increase competitiveness of territories, inequalities detected in its diffusion may have implications for economic growth, human development and the creation of wealth (Billón et al, 2009; Vicente and López, 2011; ITU, 2006). One of the consequences of the lack of broadband connections is that it generates a new divide between those who have access to a large number of applications, for which broadband is needed, and those who do not have access (Billón et al, 2009).

Previous studies on the determinants of broadband adoption have identified economic wealth as the biggest factor explaining disparities. Another important factor is human capital, especially in the case of internet which is an interactive technology and in which skills are crucial to make the most of it. Population size and its socio economic features may also contribute to explain disparities (Vicente and López, 2011). Also, empirical data has associated an age gap, in the sense that younger generations will have bigger demand for new technologies than older people (Chinn and Fairlie, 2007). Population density may also contribute, as the high fixed costs of network deployment make that highly population areas constitute attractive markets for telecommunication providers. Higher degree of services in the sectorial composition can increase

[3] For some cases of missing 2010 information, averages among data from 2009 and 2011 were used to fulfill the gaps.

the demand for broadband, as a sector which can obtain most productivity gains from the new technologies, especially services sectors which are high intensive in information (Qiang et al, 2009). Local related cultural factors may also constitute a significant factor to explain adoption (Billón et al, 2009).

Even if a wide definition of digital divide may consider a large number of technology-related variables, in this exploratory section the analysis will only consider broadband as it's the principal scope of this article. There is no public regional data on Broadband adoption at a firm level in Brazil. But, as stated by Vicente and López (2011), firm adoption is expected to be highly correlated with the general spread of broadband across the entire population. As a result, penetration across inhabitants will be used for the empirical analysis. Several authors have used penetration levels to approximate broadband infrastructure (see for instance Koutroumpis, 2009; or Czernich et al, 2011).

Broadband is defined as internet access provided at a certain high level of speed capacity. In Brazil, most internet connections at the end of the 90s and beginning of the 2000s were based on slow dial-up connections, which imposed restrictions for its usability and ability to make full use of internet applications. The introduction of broadband allowed the possibility of exploiting internet full potential. ITU or OECD defines broadband as those internet connections with speeds above 256 kbps. In this case, Telebrasil[4] available data classifies internet connections by speed considering a threshold of 512 kbps. As a result, for the purpose of this research broadband connections considered will be those that reach at least 512 kbps, which constitutes a much more realistic approximation for broadband than that of 256 kbps, which hardly serves for most nowadays applications.

Available data from Telebrasil allows considering differences in average bandwidths across regions. Fixed broadband download average speed was constructed with data which classifies subscriptions to different groups depending on its speed. In this case, averages for each interval were weighted by the corresponding penetration levels[5].

Data on labor force and on human capital were obtained from IPEA[6] and IBGE databases. As stated by Caselli (2005), data on years of schooling for population over 25 years old may seem appropriate for developed countries with a large share of college graduates, but it is not appropriate for most developing countries. After considering a diversity of alternatives, literacy rate was finally used as a measure of human capital.

To control for TFP differences across regions, it is included the percentage of urban residents over the whole population, and the sectorial composition of the economy, measured as the percentage of agriculture and services across the whole regional Value Added. To control for differences in demography structure, it is used the percentage of working-age population under 29 years old.

[4] Associação Brasileira de Telecomunicações

[5] Telebrasil offers data on fixed broadband connections across the following speed intervals: (1) 512kbps-2mbps; (2) 2mbps-34mbps; and (3) higher than 34mbps. The formula for computing average download speed for region i at time t is: $SPEED_{it} = 1.25 * \left[\frac{BB(1)_{it}}{BB_{it}}\right] + 18 * \left[\frac{BB(2)_{it}}{BB_{it}}\right] + 50 * \left[\frac{BB(3)_{it}}{BB_{it}}\right]$. Assigned speed values for (1) and (2) correspond to the half of the corresponding interval. Speed for the interval (3) is right-censored, and the election of 50 mbps is somewhat arbitrary, although results are not sensible to different approximations. The equivalence formula is 1 mbps = 1024 kbps.

[6] Instituto de Pesquisa Econômica Aplicada

Table 2
Descriptive Statistics

Variable	Mean	Min	Max	Obs
Gross Value Added per worker	14490.23 [7371.61]	5180.35 (Piauí, 2007)	46762.56 (Distrito Federal, 2010)	135
Literacy rate	88.25 [6.29]	74.26 (Alagoas, 2008)	96.84 (Distrito Federal, 2009)	135
Fixed Broadband	2.97 [3.21]	0.04 (Amapá and Roraima, 2007)	15.47 (Distrito Federal, 2011)	135
Speed	4.41 [2.82]	1.32 (Rondônia, 2007)	13.83 (Rio de Janeiro, 2011)	135
Agriculture	0.09 [0.07]	0.00 (Distrito Federal and Rio de Janeiro)	0.29 (Mato Grosso, 2008 - 2009)	135
Services	0.31 [0.05]	0.22 (Acre,2007; Amazonas and Pará, 2010)	0.47 (São Paulo, 2011)	135
Urbanism	51.63 [6.70]	36.23 (Maranhão, 2011)	65.96 (Distrito Federal, 2007)	135
Youth workforce	0.45 [0.04]	0.32 (Rio de Janeiro, 2011)	0.56 (Roraima, 2007)	135

Note: standard deviation in parenthesis

Descriptive statistics are exposed at Table 2. Important differences arise in productivity levels across regions, appearing Brasilia (Distrito Federal) as the highest productivity region. Brasilia presents some peculiarities. It was founded on 1960, in order to move the capital from Rio de Janeiro to a more central location. The difference in productivity levels between Brasilia and its most close followers (Rio de Janeiro and Sao Paulo) is substantial, possibly related of differences Its sectorial composition (its main economic activity are public administration and services) and on the fact that Brasilia is a city in a small federal district, while the other regions constitute states. On the other side, the lowest productivity region is Piauí, with a GVA per worker in 2011 which accounted for only 14% of the capital level, and 30% of that of Rio and Sao Paulo.

Broadband penetration averages 3 subscriptions per 100 inhabitants across the 5-year sample, being again Brasilia the one which reaches highest penetration level in 2011, with a penetration level of 15.47 (almost 50% of its households). There seems to be a considerable regional digital divide, as poor states, such as Amapá, reached a broadband penetration of only 0.19 in 2011 (less than 1% of households).

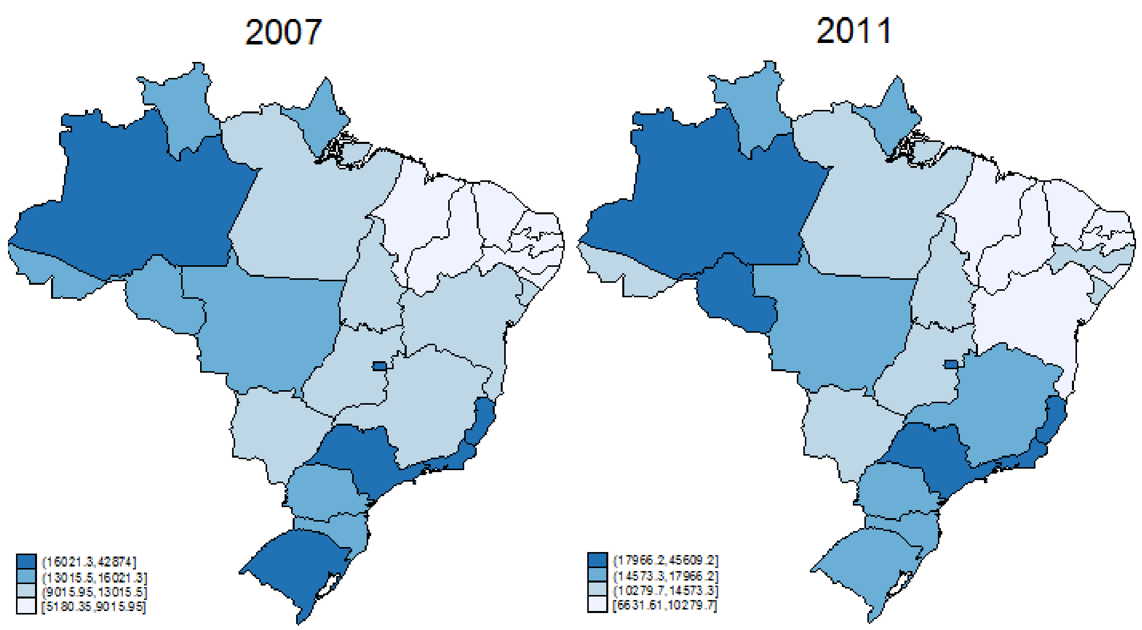
Broadband speed appears to be quickest in Rio de Janeiro in 2011, averaging 14 mbps, while lowest levels in that year were reached in Piauí (2.1 mbps), which suggest that the digital divide is present not only in quantity, but in quality levels as well. The gap in broadband average speed seems to have increased over the years, as the ratio slowest/quickest broadband speed was 0.34 in 2007 and 0.15 in 2011. The considerable differences in broadband speed across states make it important to take into account this fact when analyzing the broadband impact on productivity.

Human capital also presents some disparities across states. Highest levels of literacy rate are reached in Brasilia (97%). At the bottom, Alagoas reaches lowest levels with 74%, which means that more than a quarter of the population lack basic skills for writing and reading.

Sectorial composition is quite differentiated across states, as Brasilia and Rio de Janeiro present almost nonagricultural activity, while Mato Grosso presents almost 30% of its economy to agricultural related activities. Almost the half of Sao Paulo's economy can be attributed to services, in contrast to only 0.22% of Amazonas or Pará. Urbanism also reflects differences across states. Brasilia is the highest urban state, in contrast to Maranhao, which presents only 36% of its population living in urban areas. The age of the working population also presents regional disparities, as almost 50% of the working age population in Marañao in 2011 had 29 or less years old, in contrast to Rio de Janeiro, which presents only 32%.

Figure 1 resumes territorial disparities across productivity. While there is not a clear core-periphery pattern among regional distribution of productivity, most lagging regions appear to be concentrated at the north-east. On the other side, most productive regions appear to be located at the southeast (Rio de Janeiro, Sao Paulo, Espirito Santo), while there are poles of development at the south (Rio Grande do Sul) or at the northwest (especially Amazonas). Amazonas is an industrial state, which has attracted considerable exporting-industries in the last decades. Under a scheme of tax incentives, through the Zona Franca of Manaus, Amazonas has attracted manufacturing companies of cell-phones, electronics and motorcycles, among others.

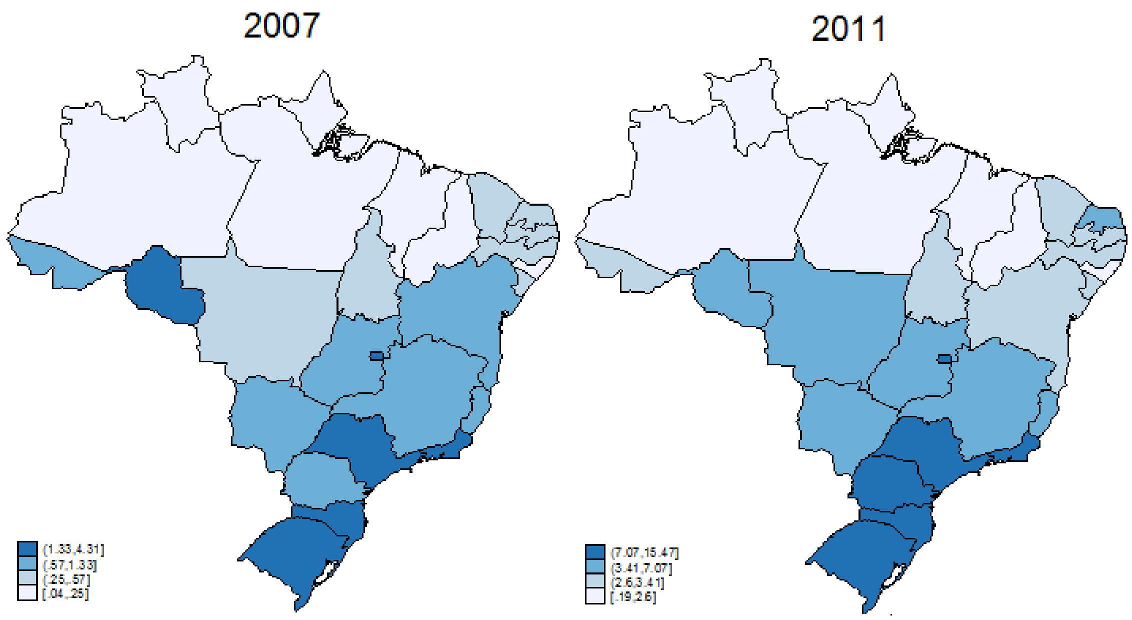
Figure 1
Gross Value Added per worker in Brazilian states



Some of the fastest growing in the period are those low-productive regions of the northeast (with the exception of Bahia), which may suggest that some process of convergence is being in place. Despite that, the spatial pattern seems to be persistent, remaining the relative positions almost unchanged between 2007 and 2011. The reason may be that a possible convergence process may take much longer than the analyzed period.

In the case of broadband penetration (Figure 2), there seems to be a more pronounced spatial pattern than in the case of productivity, with Brasilia and the southern regions reaching the highest penetration levels, while northern regions appear to be lagging behind in terms of connectivity. Billón et al (2009) found a similar pattern for European regions, as internet adoption followed an uneven spatial pattern with arising agglomeration poles. Bonaccorsi et al (2005) stated that both developed and developing countries suffer from sever regional disparities in ICT. The digital divide in Brazil seems to have a spatial pattern, as broadband penetration is not randomly distributed across space. Northern regions are mainly affected by the Amazonas forest, which probably has affected infrastructure deployment in those states. As a remarkable element, the lagging northeastern regions appear to reach in some cases acceptable levels of connectivity.

Figure 2
Fixed Broadband penetration across Brazilian states



In terms of broadband speed, the highest levels are those reached by Rio de Janeiro, Brasilia, Paraná and some of the lagging northeast regions. The fact that some of the low-productive regions were the fastest growing in the period, and present reasonable levels of broadband penetration and speed, may contribute to raise the question if the new technologies may have contributed to its recent development.

Figure 3

Fixed Broadband download speed across Brazilian states

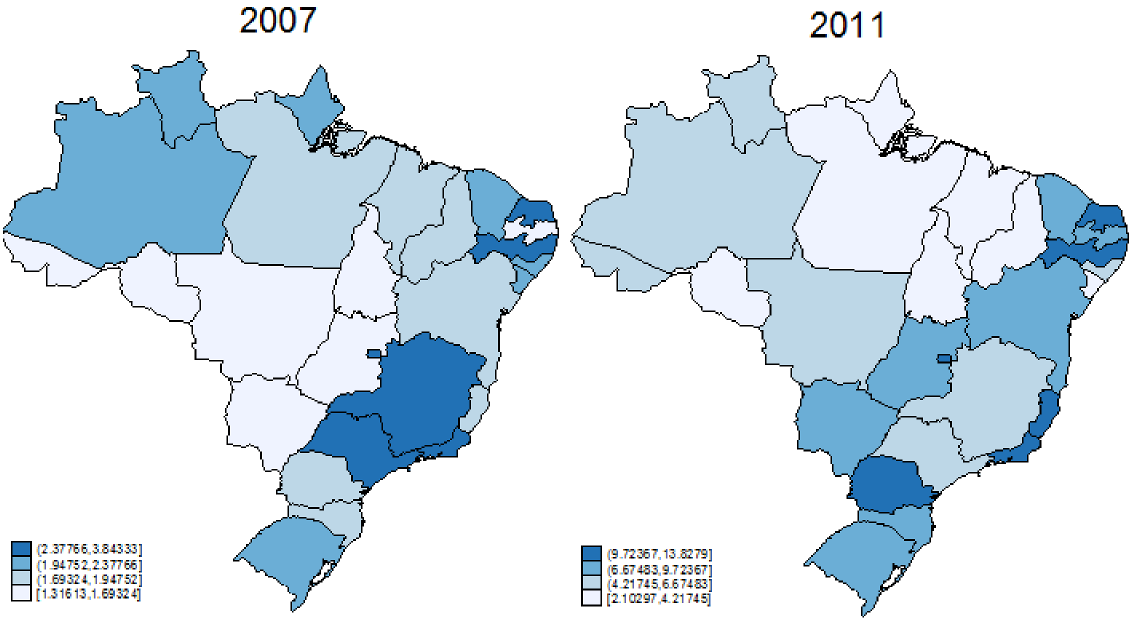
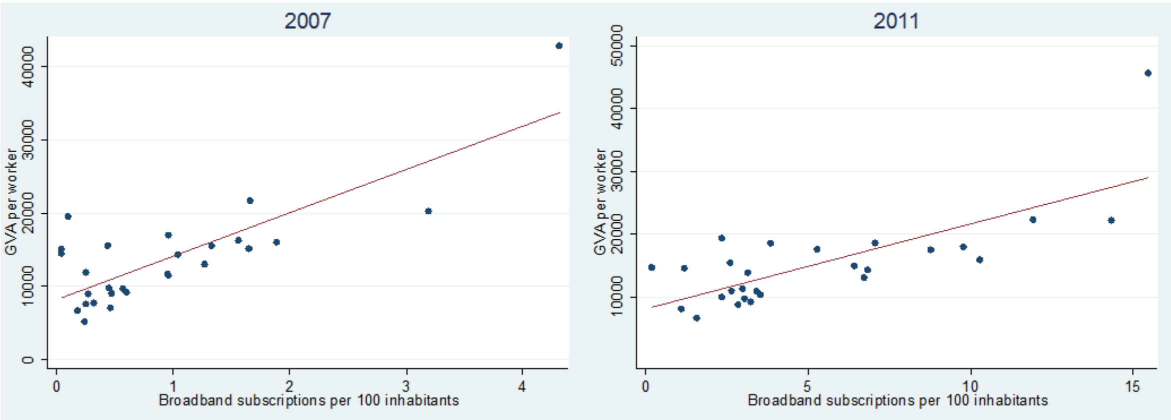


Figure 4 plots broadband penetration and productivity. Even if that correlation does not necessarily indicate a directionally causality, it provides evidence of a positive correlation among both variables, which is stable over the period considered.

Figure 4

Correlation between Productivity and Broadband penetration



5. Results

The empirical analysis will consist on the econometric estimation of the proposed model on diverse specifications. As the empirical specification makes impossible to recover *α,* this parameter will be determined by the capital share on the income in Brazilian national accounts. In that sense, Feenstra et al (2013) using Penn World Table data found that the labor share in the income in Brazil averaged 0.55 in the period 2007-2011. Under the assumption of constant returns to scale, this implies α=0.45, which will be used to recover the structural parameters. Table 3 resumes estimations of the base model assuming no interaction between broadband penetration and local attributes. All estimations are performed with robust standard errors.

Table 3
Estimation Results of base model

Estimation	[1]	[2]	[3]	[4]
Literacy rate	0.0197**	0.0218***	0.0118*	0.0188***
	[0.0083]	[0.0070]	[0.0069]	[0.0065]
ln(Broadband)	0.0364***	0.0368***	0.0553***	0.0714***
	[0.0125]	[0.0103]	[0.0127]	[0.0255]
Agriculture		0.1511		0.0007
		[0.2748]		[0.4277]
Services		-1.0189**		-1.1862***
		[0.4073]		[0.3359]
Urbanism		-0.0133***		-0.0146***
		[0.0023]		[0.0029]
Youth workforce		0.1316		1.1027
		[0.4562]		[0.7561]
Year 2009		-0.0122*		-0.0133
		[0.0070]		[0.0092]
Implied ϕ	0.0200	0.0202	0.0304	0.0393
Implied γ	0.0108	0.0120	0.0065	0.0103
Fixed Effects	Yes	Yes	Yes	Yes
Observations	135	135	132	132
R-sq (within)	0.50	0.66	0.46	0.61
Method	LS	LS	IV	IV

Note: *p<10%, **p<5%, ***p<1%. Robust standard errors in parenthesis. Instruments for Broadband in IV: telephone fixed voice lines per 100 inhabitants (lagged 5 years), and population density at the beginning of the XX century (census 1920-1950).

Estimation [1] in Table 3 resumes Least-Squares results assuming that all region specific differences in TFP, accounted by Ω_i are time-invariant, approximated by state fixed effects. Results suggest a positive and significant incidence of human capital on productivity, as expected. Broadband is found to be significant at 1% level, with elasticity levels which suggest that a 10% increase in penetration can be related with a 0.2% of increase in productivity, as denoted by the implied parameter ϕ. As stated by other studies (Czernich et al 2011; Koutroumpis, 2009) broadband effect appears to be contemporaneous to the diffusion of broadband. Although the magnitude is similar to other empirical research in the literature, additional estimations will be performed to evaluate the robustness of the results.

Estimation [2] in Table 3 will add controls to [1], this is to assume that not all regional specific differences in Ω_i are time-invariant. As a result, beyond region specific fixed effects, further variables will be considered as potentially having an incidence in productivity. There are added variables to account for sectorial composition (percentage of agricultural and services activities in local GVA), degree of urbanism, age of the workforce and a dummy variable to account for economic cycle. As stated by Cardona et al (2013), taking into account business cycle effects is manageable given long enough time periods, which is not the case of this dataset. As a result, a dummy variable will be added for year 2009, in which the Brazilian economy experienced a one-off contraction as a result of the international crises. This variable will absorb external shocks related to the recession. Results in [2] suggest similar coefficients for broadband, proving that the impact is robust to controls.

A common critique of ICT and broadband estimations is that sometimes the results determine correlation rather than a causality effect on productivity, because investment in ICT may be considered a driver, but also a result of productivity and economic growth (Cardona et al, 2013). This possible reverse causality may arise because individuals in high-income economies may also have higher resources to pay for broadband. Some authors exploit the structure of panel data by using lagged variables for ICT (Bloom et al, 2010; Brynjolfsson and Hitt, 1995; Hempell, 2005; Tambe and Hitt, 2001). Other strategies may be structural multi-equation models (Koutroumpis, 2009; Roller and Waverman, 2001), or instrumental variables with a first stage diffusion equation (Czernich et al, 2011; Bertschek et al, 2013).

Bertschek et al (2013) firm-level analysis uses DSL availability as an instrument for broadband. Their results suggested that instrumental variables approach resulted in higher coefficients for broadband incidence in productivity, although less precise than OLS as the standard errors increased, leaving broadband as weakly significant. In Czernich et al (2011) country-level analysis uses fixed-line voice telephony and Cable TV pre-existing networks as instruments for broadband. Its estimations suggested that IV results are slightly larger than OLS, concluding that OLS regressions are downward biased.

Following Czernich et al (2011), in the empirical specification will build on the idea that most common broadband roll-out (i.e.: ADSL or Cable Modem) rely on the cooper wire of pre-existing voice-telephony networks. As stated by Czernich, the required access to an existing infrastructure built for other purposes, such as that of fixed telephony, make this a suitable instrument for this estimation strategy. The instrument in this case will be the number of voice-telecommunication fixed access lines per 100 inhabitants five years before. In addition, as broadband deployment may depend on demographic factors, population density will be added as instrument, but using variables from the beginning of the last century (census 1920-1950). The instruments were lagged considerably to break any possibility of being affected by contemporary shocks.

Results for IV estimations are exposed at columns [3] and [4] of Table 3. In both cases, the Hansen statistic, which test the exogeneity of the instruments do not reject the null hypothesis of exogeneity. Weak-instruments contrasts also suggest the validity of the chosen instruments. Results of the estimations through IV suggest, if anything, that the incidence of broadband is even higher. This fact replicates the statements by Bertschek et al (2013) and Czernich et al (2011) in the sense than OLS results may be downward biased. In fact, productivity-broadband elasticity reaches 0.03 in the model with no controls and 0.04 when adding controls. The fact that the coefficients increase from LS to IV, and even increase further when adding controls, provides further support to the hypothesis that broadband has impacted on productivity in Brazil, suggesting a causality direction in that sense.

Once the impact of broadband on Brazilians productivity seems to be verified, forthcoming estimations will relax the assumption that the impact is uniform across states, which means to define TFP as in [2´]. To take into account possible differences in the impact of broadband, regions will be classified in groups according to its level of development, measured through labor productivity. The 27 states can be easily divided into three groups of 9 regions, according to the average productivity levels in the sample. Regions classification is exposed at Table 3.

Table 3
Region clustering according to productivity

Low-Productive regions	Medium-Productive regions	High-Productive regions
Piauí	Tocantins	Mato Grosso
Maranhão	Goiás	Rondônia
Ceará	Pará	Santa Catarina
Paraíba	Mato Grosso do Sul	Espírito Santo
Alagoas	Minas Gerais	Rio Grande do Sul
Rio Grande do Norte	Acre	Amazonas
Bahia	Amapá	Rio de Janeiro
Pernambuco	Paraná	São Paulo
Sergipe	Roraima	Distrito Federal

Forthcoming estimations will be performed through Least Squares as it provides a lower bound than IV. Regions will be classified by its level of development according to Table 3, classifying high-productive as the base scenario, and adding dummy variables LP (for low-productive) and MP (for medium-productive). The respective associated parameters will be represented by Φ (base scenario), Φ_{LP} and Φ_{MP}.

Estimation [1] in Table 4 considers uniquely the level of development as a source for differences in the impact of broadband on productivity (restricting $\delta=\lambda=0$). Results suggest important differences among regions. Every region benefits from broadband (as Φ is significant and equals 0.014), but low-productive regions appear to obtain much more productive gains through broadband than medium and high productive regions (as Φ_{LP} is significant and equals 0.025). On average, after a 10% increase of broadband penetration developed regions in Brazil seem to increase productivity in 0.14%, while more underdeveloped regions increase productivity by 4%.

Additional productivity gains for medium developed regions are positive but no significant. On average, a possible pattern may suggest that the impact of broadband on productivity declines as regions become more developed.

Further estimations will relax some of the restrictions imposed before. Estimation [2] allows regions reaching a certain critical mass to get benefit from network externalities. Lowest thresholds considered by other authors at OECD countries were found to be far from Brazilian levels at this stage (for instance, Koutroumpis (2009) considers as critical the threshold of 20% penetration per inhabitant, while Czernich et al (2011) measure network externalities from a 10% level. For Brazil, after some considered alternatives, a minimum threshold was decided, as 6.25%

penetration, a level which means 20% of households with broadband connection[7]. Regions reaching that threshold will be assigned with $Mass = 1$, while regions below will get $Mass = 0$.

Table 4
Results allowing variations for region groups

Estimation	[1]	[2]	[3]	[4]	[5]
Literacy rate	0.0111	0.0098	0.0114	0.0103	0.0149**
	[0.0079]	[0.0077]	[0.0076]	[0.0076]	[0.0071]
ln(Broadband)	0.0258**	0.0143	0.0161	0.0116	0.0271*
	[0.0120]	[0.0120]	[0.0123]	[0.0124]	[0.0151]
LP*ln(Broadband)	0.0462**	0.0599***	0.0495***	0.0582***	0.0378*
	[0.0171]	[0.0176]	[0.0165]	[0.0171]	[0.0195]
MP*ln(Broadband)	0.0076	0.0147	0.0117	0.0153	0.0007
	[0.0191]	[0.0172]	[0.0178]	[0.0173]	[0.0170]
Mass*ln(Broadband)		0.0177**		0.0129*	0.0069
		[0.0067]		[0.0072]	[0.0062]
Quality*ln(Broadband)			0.0002**	0.0001	0.0000
			[0.0001]	[0.0001]	[0.0001]
Agriculture					0.1277
					[0.2910]
Services					-1.2408***
					[0.4058]
Urbanism					-0.0101***
					[0.0024]
Youth workforce					0.1192
					[0.4440]
Year 2009					-0.0095
					[0.0062]
Implied ϕ	0.0142	0.0079	0.0089	0.0064	0.0149
Implied ϕ_{LP}	0.0254	0.0329	0.0272	0.0320	0.0208
Implied ϕ_{MP}	0.0042	0.0081	0.0064	0.0084	0.0004
Implied δ		0.0097		0.0071	0.0038
Implied λ			0.0001	0.0001	0.0000
Implied γ	0.0061	0.0054	0.0063	0.0057	0.0082
Fixed Effects	Yes	Yes	Yes	Yes	Yes
Observations	135	135	135	135	135
R-sq (within)	0.55	0.57	0.57	0.58	0.69
Method	LS	LS	LS	LS	LS

Note: *p<10%, **p<5%, ***p<1%. Robust standard errors in parenthesis.

Estimation [2] in Table 4 suggest that low developed regions still gain the most productivity benefits from broadband. In contrast, the base scenario appears to be not significant, once controlling for critical mass. Critical mass appears to be important, as the parameter associated is

[7] Brazilian households have in average 3.2 persons

positive and significant at 5%. This suggests that regions after reaching the stipulated critical mass increase the impact of broadband on productivity by 0.009. These results cannot be interpreted as that medium and highly developed regions do not obtain benefits from broadband, but those benefits may be mostly associated to network externalities. In contrast, underdeveloped regions get a benefit independently from the critical mass effect.

Estimation [3] in Table 4 allows broadband quality differentials to have an incidence on productivity. As seen in Figure 3, low productive regions, located at the northeast, reach acceptable average speed levels for its broadband networks, suggesting that this may contribute to these regions extracting more externalities from broadband. To approximate quality, the measure to be used will be the square of average speed, following Rohman and Bohlin (2013). Results suggest that low developed regions remain benefiting from a higher economic impact from broadband than other regions. Medium and highly productive regions again reach non-significant levels. Broadband speed seems to be important, as the associated parameter is significant at 5% level. As in the case of critical mass, higher quality may be contributing especially to medium and high productive regions reaching benefits from broadband.

Estimation [4] in Table 4 considers at the same time critical mass and quality differentials. As expected, highly multicolinearity levels between quality and critical mass affect the coefficients and increases the standard errors. Despite that, the parameter associated to low productive regions remains positive and highly significant, while critical mass remains significant at the 10% level. Estimation [5] adds the controls for Ω_i, which generates again high colinearities in the model. Despite that, the base level associated parameter for broadband is positive and significant, while the parameter for low developed regions is also significant (in both cases at 10% level).

Results again confirm that most underdeveloped regions appear to obtain a higher impact from broadband, in this case after controlling for differences in sectorial composition, degree of urbanism, age of the workforce and 2009-related shocks.

It is important to try to address why most underdeveloped regions are getting more economic impact from broadband. A possible explanation can be related to the fact that the technological change derived from broadband deployment in a poor region seems to be much bigger than in highly developed regions, which already had good infrastructure and communications endowment. In contrast, for poor regions, the impact on the social and business environment may be bigger. Perhaps high productive regions in Brazil may have already made a difference in their economies because of broadband.

Most underdeveloped regions in this sample appear to be located at the north-east of the country, which do not exhibits most geographical complications for infrastructure deployment. In contrast, northwest regions are heavily affected by the Amazonas forest, which may have slowed the infrastructure deployment. At the same time, most underdeveloped regions at the north-east have an important degree of services among its sectorial composition. Combining those attributes it’s not so surprising that these regions had reached better connectivity levels than other medium-productive regions (see Figure 2). That may have contributed to those regions benefiting more from broadband.

6. Conclusions

This paper appears to provide robust evidence that the impact of broadband on productivity is not uniform across national territories. In fact, at least in Brazil, broadband seems to be yielding higher productivity gains for less developed regions, a result which is robust after controlling for differences in quality, network effects, human capital, sectorial composition, degree of urbanism and the age of the workforce. Even if a convergence analysis remained out of the scope of this paper, these results may suggest that broadband connectivity may constitute a factor favoring regional cohesion in Brazil. Although to confirm that asseveration further research will be required, especially when long-enough time series data is available to perform a growth-regression analysis. In any case, broadband connectivity seems to be a source of productivity gains in Brazil, something which brings empirical support to the public program of connectivity "Programa Nacional de Banda Larga", currently being deployed in Brazil.

To conclude, some policy implications may be derived from the analysis. The importance of broadband for regional development makes that all level of governments should follow policies that encourage broadband deployment. Although referring to the case of Europe, Barrios and Navajas (2008) stated the importance to adopt, together with country-level initiatives, regional policies, because the nature of technological change and innovation have a string regional component which make that public policies must be designed taking that into account. In Brazil, some states have started to follow this strategy, as for instance Paraná and Amapá which have launched state-based broadband public plans, in a complementary strategy as the national plan. Barrios and Navajas (2008) state the importance of regional cohesion policy programs considering the relevance of ICT infrastructure, aiming to favor the attractiveness of lagging regions. They even call for differentiated policies, even among regions within the same countries. Regional policies should also promote ICT skills and the use of ICT by SMEs (Barrios et al, 2008).

In this context, investment from service providers in broadband infrastructure is critical, both in terms of coverage and speed. As stated by Crandall et al (2009), it is critical that regulatory policies do not reduce investment incentives for carriers. In particular, policy makers should adopt measures that promote, or at least do not inhibit, the growth of broadband. In density-populated areas private competition will surely provide the required incentives which will lead to higher investments and better connectivity. In those markets, it will be necessary from federal and state governments to reduce entry barriers and promote investment by incumbents and new service providers. In contrast, in distant areas, with low levels of population density, or affected by geographical conditions, surely public intervention will become vital for infrastructure deployment. At those cases, universalization policies will become crucial. As stated by Frieden (2005), broadband investment requires of important levels of public and private cooperation.

Policy will also need to promote connectivity from the demand-side. Lower prices will be necessary to increase penetration, because as stated by Galperin and Ruzzier (2013), broadband demand is elastic. Additionally, to maximize demand and social returns to broadband deployment, policymakers should address a lack of ICT-related skill deficiencies in the workforce.

Downloading speed is, as seen before, important to enhance the economic impact of broadband, at it will become more important in the future, as data traffic through the networks is increasing and will start to strain current infrastructures.

Although not addressed by this research, mobile broadband may also constitute an opportunity to close the digital divide, especially through its potential to connect isolated distant areas (Katz, 2012). In that sense, spectrum allocations will be required to provide necessarily resources for deployment of new generation services as LTE.

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