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Fixed broadband connections and economic growth: a dynamic OECD panel analysis

Angelo Castaldo* Alessandro Fiorini∆ Bernardo Maggi+

Abstract: *Technological innovation is viewed as a major stimulus for economic growth. High-speed internet access via broadband infrastructure has been experiencing a prompt development since the end of 90s, thanks to the deployment of both fix and mobile technologies. The present study investigates on the behavior of broadband diffusion as a technological determinant of economic growth in the main OECD countries. The estimations performed allowed to control and interpret the time evolution of the phenomenon according to the achievable target of growth, as resulting from the promotion of broadband internet connections. Our main goal is to provide evidence of a relevant - in quantitative term - relation between broadband diffusion and economic dynamics in the short, medium and long run.*

Key words: Fixed broadband access, economic growth, technology diffusion, dynamic panel
JEL classification: L96, O47, O33, H54

1. Introduction

Information and Communication Technologies' (ICT) networks are commonly recognized as crucial drivers for economic and social development. Serving as communication and transaction platforms they represent, since their origin, a key component for both creation and diffusion of knowledge through which individuals, firms and governments can interact in a more efficient way (von Hayek, 1945). Given the high positive spillovers, ICT infrastructures can determine structural changes in an economic system mainly supporting factor's productivity growth across all sectors (Katz et al. 2010; Greenstein and McDevitt, 2011; Stryszowski, 2012).

There is a widespread belief that internet diffusion leads to an significant impact on socio-economic variables. Internet, in particular, rose up as a facility devoted to the improvement of communication systems but has soon turned into a ubiquitous technology supporting all sectors across the economy (Oz, 2005; Flamm and Chaudhuri, 2007). Internet, therefore, is now widely considered as an essential platform, besides electricity, water and transportation networks and can now be considered as a 'general purpose technology' (Holt and Jamison, 2009; Majumdar et al., 2009). In this field of research, as a consequence of the rapid technological innovations achieved, the debate during the last twenty years has naturally shifted on broadband (BB) internet access. Advanced communication networks are a key component of innovative ecosystems and strongly support economic growth (Czernich et al., 2011; Koutroumpis, 2009; Qiang et al. 2009; Crandall et al., 2007; Datta and Argawal, 2004; Roller and Waverman, 2001). Broadband networks also increase the impact and efficiency of public and private investments that depend on high-speed communications. Broadband is seen as a complementary investment linked to other infrastructures such as buildings, roads, transportation systems, health and electricity grids, allowing them to be "smart" and save energy, assist the aging, improve safety and adapt to new ideas (OECD, 2009).

The term broadband, however, entails a number of complex issues in terms of technologies, speeds and quality of services (ITU, 2011). Broadband is commonly used to define a form of high speed access to

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communication technologies. International Telecommunication Union (ITU) fixes at 256 *kbit/s* the lower bound to recognize a broadband internet connection, including alternative technologies such as cable modem, Digital Subscribers Line (*xDSL*) and fiber, in case of portable internet; satellite subscriptions, terrestrial fixed wireless subscriptions and terrestrial mobile wireless subscriptions in case of mobile broadband connections. The Organization of Economic Cooperation and Development (OECD) assumes 256 *kbit/s* in at least one direction. Even though the bit rate set by ITU and OECD is the baseline for the most national institutions' standards, broadband definition seems to be an open issue[1]. Setting a minimum level based on speed of connection for the definition of broadband is certainly a complicated task, because both technologies and services/applications evolve; this leads to a difficult comparability among similar variables over time.
Socio-economic structural reforms seem to be a key policy factor in order to bank the effects of the severe economic downturn suffered by Nations from 2008 (e.g. Horizon 2020 - European Digital Agenda for UE and Competes Act (PL 110-69) for US). The significant penetration and improvement of ICT broadband (BB) facilities can certainly play a leading role in conjugating innovation in terms of productivity gains, thus strategies adopted by policy makers for setting up recovery patterns should be viewed as opportunities for targeting investment in strategic areas such as broadband (OECD, 2009)[2].
This paper provides a contribution to the measurement of the impact of broadband penetration (fixed internet connections equal or faster than 256 *kbit/s*) on growth. More specifically our goals and advancements in the literature are: a) to model in a proper dynamic way the impact of broadband penetration on GDP per capita according to the time adoption required to implement the ICT spillover; b) to evaluate the associated velocity of convergence to the new equilibrium - if stable - and then the time response to its attainment; c) to test the relevance of being a leader or a follower innovation country; d) to test the effect of the actual economic crisis; e) to measure country specific short, medium and long run impact of BB on GDP per capita.
The paper is organized as follows. In Section 2 a review of the main literature concerning broadband/ICT technologies and economic growth is presented. Section 3 & 4 describe models' equations and econometric methodology. Section 5 clarifies the main elements of the dataset and variables adopted for the estimations. Section 6 presents the estimations results. Section 7 shows the main policy implications. Finally, Section 8, draws the main conclusions.

2. Literature survey

Our work is placed in the endogenous set up of growth models with externalities pioneered by Lucas (1988), Romer (1990) and Barro (1991). Other seminal contributions funded on a technologically unspecified endogenous growth model, elaborated by Mankiw et al. (1992) and Aghion and Howitt (1992), generated a consistent field of research based on an equilibrium approach appositely specified in order to study the relationship between broadband penetration and GDP.
The impacts of broadband infrastructures on economic growth have been discussed in a large number of works. Overall results support the view that broadband access enhances economic growth and that causality impacts are real and measurable. Several studies, however, have been considered biased due to common time trends, omitted variables, simultaneity and reverse causality.
Roller and Waverman (2001) investigated on growth across 21 OECD countries from 1970 to 1990 and showed that almost one third of the capita GDP growth (0.59 of the 1.96 percent per year growth rate) was to be attributed to investments in telecommunications infrastructures. Moreover, the study gives evidence of important fixed effects and of reverse causality issues.
Datta and Agarwal (2004) empirically evaluate, in a sample of 22 OECD countries, the impact of telecommunication infrastructure (access lines per 100 inhabitants) on economic growth. Authors implement a panel data and implement a dynamic fixed-effect method estimation technique; fixed effects

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[1] For example, the US Federal Communication Commission (FCC) identifies a broadband connection as *"transmission service* […] *enables an end user to download content from the Internet at 4 Mbps and to upload such content at 1 Mbps over the broadband provider's network"*. In Djibuti and Morocco, so as in other developing countries, the bit rate is set at 128 *kbit/s* (ITU, 2011).
[2] As remarkable example Korea and Finland experienced high positive returns as leading countries in the diffusion of broadband technologies (Kim *et al.*, 2010).

are specified in order to deal with country specific differences in aggregate production functions. The results show that telecommunications infrastructures are statistically significant and highly positively correlated with growth in GDP per capita; moreover, results are robust after controlling for investment, government consumption, population growth, openness, past levels of GDP and lagged growth. However they miss in testing an equilibrium relationship but only asses whether a convergence process towards an unspecified long run condition is in action. Further this is done without emphasizing on the time through which such a convergence takes place.

Gillet et al. (2006) found that the availability of broadband connections may explain relevant gaps in growth and employment. In particular, the approach followed uses a cross-sectional panel data set in order to catch the effects of broadband on communities in the US between 1998 and 2002.

Crandall et al. (2007) found a strong association between broadband (BB) adoption and economic prosperity in United States of America, through the channel of job creation and GDP. During the period 2003-2005, they estimate that a 1% increase in BB penetration, produced an increase in the annual rate of employment, in industrial sectors, from 0.2 up to 0.3 percentage points, as regards the effects of BB deployment on GDP, results appear to be less precise.

Holt and Jamison (2009), in surveying the main studies on BB and GDP in the case of United States of America, observe a positive impact on GDP of BB but considers the impact not precise. In the opinion of the authors, the uncertainty on the impact are mainly due to two reasons: a) impacts evolve in time with nonlinearities, even going through periods of negative growth and b) endogeneity can affect workforce change, broadband adoption and, more generally, other determinants.

Cznernich et al. (2011) cope with such questions by better identifying the penetration rate with the use of a logistic function based on available physical infrastructure. They estimate the effect of broadband infrastructure on economic growth relying on a panel dataset of OECD countries in 1996–2007. Their aim is to estimate a long run equilibrium *à la* Mankiw et al. (1992) throughout a first difference approach. Other similar studies that seek to study an equilibrium relationship are, among others, Bresnahn et al. (2002), Bloom and Van Reenen (2007) and Cappelli (2010).

From the cited literature, however, there are still some relevant open questions that need to be further addressed. First, the adoption of an equilibrium approach misses the adjustment phase both in the timing pattern of growth and in the attainability of the equilibrium itself. Second, equilibrium (long run) relationships require specific empirical treatment (Breitung and Pesaran, 2008) to be accurately tested on long time series that are not available for the dataset used by the literature till now. Moreover, neither suffices to this aim a first difference approach. Third, from the criticalities aforementioned, doubts on the correct treatment of the endogeneity arise.

3. Model equations and strategy of analysis

As underlined in the literature survey, the time adoption is peculiar to the problem of broadband penetration that we want to address in capturing the effect on growth. As said, traditional growth models, in this area, derive from a dynamic context but are confined to the analysis of the steady state without focusing, when a theoretical long run relation is specified, on the transitional dynamic. This is the case of the Mankiw et al. (1992) set up and of the subsequent stream of works cited in the previous section. In the shade of such a framework, our approach, even though grounded on the Mankiw et al. (1992), focuses on the dynamic pattern of the phenomena, thus, deriving the equilibrium relationship moving from an adjustment process and evaluating its attainment to the equilibrium. Further, we conceive the broadband penetration as playing a crucial role inside the technological component and extend the equilibrium relation in order to examine the incidence of the actual economic crisis.

The steady state relation we intend to test is therefore

(1) $y_{it}^{ss} = a_t + \alpha_l l_{it} + \alpha_{hk} hk_{it} + \alpha_k s_{it}$, $i = 1, \ldots, N$; $t = 1, \ldots, T$

(2) $a_t = \alpha_0 + \alpha_b F_{it}^b \left(MOB\_NET_i, TEL\_NET_i, CAB\_NET_i, t, \mathbf{\Theta} \right) + \varepsilon_{it}$

(3) $\Delta y_{it} = \delta \left(\alpha_0 + \alpha_b F_{it}^b \left(MOB\_NET_i, TEL\_NET_i, CAB\_NET_i, t-1, \mathbf{\Theta} \right) + \alpha_{LF} LF + \alpha_l l_{it} + \alpha_{hk} hk_{it} + \alpha_k s_{it} - \alpha_{D_c} D_c - \alpha_{yt-1} y_{it-1} \right) + \varepsilon_{it}$

the symbols in lower case characters indicate that variables are in natural logarithms, *i* and *t*, countries and time. In eq. (1) they are: steady state output per worker (y^{ss}), technical progress (*a*), workforce (*l*), human capital (*hk*), investments (*s*). In eq. (2), $F^b(.)$ models the broadband penetration as a function in order to take into account the relevance of existing communication infrastructures (e.g. fixed network, mobile network and cable) on the actual broadband penetration pattern and **Θ** is a parameters vector to be estimated. $F^b(.)$, thus, is the function that represents the broadband penetration, *B*, given by the percentage of broadband subscribers over 100 inhabitants (connections with downstream speeds equal or greater to 256 kbit/s). Equation (3), finally, defines our Adjustment Equilibrium Model Approach (ADMA), that defines the adjustment process at time *t* of the actual GDP per capita (*y*) with respect to its steady state value of the previous period *t*-1. This is in line with Islam (1995), and allows to capture short run autoregressive behavior of the dependent variable.

Moreover, in the latter, in order to further qualify such an adjustment in disequilibrium we also introduce two dummy variables: D_c and *LF* refer respectively to the years of economic financial crisis and to the countries in the position of leader or follower on the path of technology adoption.

In order to test in a comparative way our approach with the one most implemented by the ongoing literature (Cznernich et al., 2011) we also estimate, with equation (4), our steady state Equilibrium Model Approach (EMA) based on the Mankiw fashion. Thus we estimate equation (4) as follows,

$$(4)\quad \Delta y_{it} = \alpha + \alpha_b B_{it} + \Delta\alpha_l l_{it} + \Delta\alpha_{hk} hk_{it} + \Delta\alpha_k s_{it} + \alpha_t T_{it}^B + \alpha_y y_{i0} - \alpha_{bt-1} B_{it-1} + \varepsilon_{it}$$

The ongoing empirical literature tries to estimate directly the equilibrium relation of eq. (1) by considering the "difference in difference" relation (eq. 4) and introducing accessory control variables to disentangle from the data the long run condition which, however, does not reflect necessarily the actual pattern. The use of control variables help to compensate the absence of an adjustment process linked to technology here represented by broadband. In Cznernich et al. (2011) these controls are time variables such as, the exogenous years (T^B) since the beginning of the phenomenon under focus, i.e. broadband penetration and the country-specific initial GDP per capita condition (y_{i0}). They respectively take into account the out-of-steady-state dynamics and the - neoclassical - convergence hypothesis of countries to a common steady-state. Of course the former effect may well go beyond the exogenous effects and the latter does not suffice in describing the time pattern of the adjustment process because it is only able to test the convergence hypothesis. From a methodological point of view, anyway, the strategy of using first differenced variables does not allow to obtain unequivocally a steady state relation since the estimated relation could be of a long run as well as a short run. Furthermore, given that the length of the time series does not allow for powerful tests of cointegration and stationarity of the variables, the differentiation adopted in the estimation seems superfluous. For the same reason (i.e. for the impossibility to invoking the stationarity of the variables and even less their cointegration) it is reductive to confine the endogeneity problem to broadband penetration rate, while it is to be referred to all the set of variables. Yet, even more curious, simply because it is a constant term, is the inclusion of the initial condition of the broadband penetration in the endogeneity problem. As for the introduction of the controls, their meaning, in a differenced relation, will be different from original purposes since the time and the fixed GDP variables will result, in terms of the non-differenced relation, squared and linear respectively.

We qualify more and solve such points by proposing an ADMA (eq. 3) which considers the adjustment process towards the equilibrium based on instrumental variables. In such a way we are capable both to test and assess on the nature (equilibrium or short run relation) of the equation estimated and deal in a consistent way with the problem of endogeneity. Moreover, considering an adjustment process allows to cope with the nonlinear effects determined by broadband penetration on growth due the time adaption required for the productive system in order to implement the new technologies (Holt and Jamison, 2009).

Therefore, our contribution is: 1) to provide empirical evidence that the Mankiw et al . (1992) model actually is of long run but need the consideration of an appropriate adjustment process to be estimated, 2) to calculate the short, medium and long run effects of the variables on growth, 3) to pin down the contribution to growth of the leaders and the followers countries in adapting new technologies, 4) to provide explanations to the somehow puzzling result of a negative trend obtained in the recent literature.

As regards the way of modeling the "profile" of time evolution assumed by broadband diffusion, $F^b(.)$, penetration rate for many OECD countries suggests that the pattern of broadband technologies' diffusion mimic a 'S-shaped curve' as indicated by the theory of diffusion of innovations (Everett; 1995) and technologies (Comin *et al.*; 2006). Among the several functional expressions through which such a curve may be formalized, the logistic is one of the most employed (Gruber, 2001; Gruber and Verboven, 2001; Comin *et al.*, 2006; Singh, 2008; Lee *et al.*, 2011). Moreover, the effects of network externalities play a leading role as determinants of the diffusion (Gruber and Verboven, 2001). Connections develop as the result of an exponential dynamic. At a certain starting period, the broadband diffusion process concerns few people. As the number of subscribers begins to increase, a larger amount of people will be involved by the valuation of the opportunity to access to interact with the other users, triggering a further increase in the number of subscribers. Conversely, when the number of users approaches the total number of potential adopters in the market, the rate of growth of new subscribers declines down to zero, leading the number of total subscribers up to a saturation point due to the congestion, or low valuation for broadband services, among the remaining non-subscribers (Lee *et al.*; 2011).
The logistic function, $F_{it}^{b}(.)$, may be represented in the Fisher-Pry modality (Fisher and Pry, 1971; Meyer *et al.*, 1999) as

$$(5)\ \ln\left(\frac{\alpha_{MOB}MOB\_NET_i+\alpha_{TEL}TEL\_NET_i+\alpha_{CAB}CAB\_NET_i}{F_{it}^{b}(.)}-1\right)=-\delta(t-\tau)$$

and we have defined its maximum over time and for each country as

$$(6)\ \max_t B_{it}=\alpha_{MOB}MOB\_NET_i+\alpha_{TEL}TEL\_NET_i+\alpha_{CAB}CAB\_NET_i$$

where d is the "steepness" of the sigmoidal curve, i.e. the approximate average growth rate at any time unit and t is the time when the curve reaches half of $\max_t B_{it}$, i.e. the midpoint of the growth trajectory.
The choice of our variables is relevant in that will be proved both with a greater explicative capacity and with a more precise focus on the actual low-pace growth within our panel of countries with respect to the relevant literature.

4. Econometric methodology

Given the time dimension and the lagged effect of the models presented in Section 3, our straightforward method is the Arellano-Bond dynamic panel GMM estimator with one lag, which in this case displays as:

- the estimation equation

$$(7)\ Z'\Delta Y=Z'\Delta Y_{t-1}\alpha_{Y_{t-1}}+Z'\Delta\underline{X}\,\underline{\beta}+Z'\Delta\zeta$$

where vectors and matrices refer to variables stacked by space and time;

- Among $\underline{X}'_{it}$ the strictly (i.e. lagged) predetermined (k_1=4) together with the exogenous (k_2=2, i.e: *LF*, *j*) regressors[3] are used to obtain the necessary instruments ($\underline{Z}'_i$)

$$(8)\ \underline{X}'_{it}=\left(f_{it}^{b}(.),s_{it},hk_{it},l_{it},y_{it},lf,j\right),\ E\left(\underline{X}'_{it}\underline{\varepsilon}_{is}\right)\neq 0 \text{ with } t\geq s, \text{ and } X_{it}\neq t,j,\ j=1,\dots\dots\dots,1;$$

- the parameters vector is

$$(9)\ \underline{\beta}'=\left(\alpha_l,\alpha_{hk},\alpha_k,\alpha_{d_c},\alpha_0,\alpha_b,\alpha_{lf}\right);$$

- the errors term structure is

$$(10)\ \Delta\zeta_{it}\ \square\ \text{MA}(1), i=1,\dots.N, t=1\dots T$$

[3]Of course *LF* and *j* are non stochastic and therefore strictly exogenous ($E\left(\underline{X}'_{it}\underline{\varepsilon}_{is}\right)\neq 0\forall t,s$).

(11) $\underline{V}_i = E\left(\Delta\zeta_{it}\Delta\zeta_{it-k}\right) = \begin{cases} 2\sigma_\varepsilon^2, k=0 \\ -\sigma_\varepsilon^2, k=1 \\ 0, k>1, k=1,..,T-3 \end{cases}$, of order T-2, and $\underline{V} = I_N \otimes \underline{V}_i$ of order $N(T$-2);

- the instruments matrices are

(12) $\underline{Z} = I_N \otimes \underline{Z}_i$ of order $N(T$-2)L

where $\underline{Z}'_i$ is the individual instrument matrix of order (T-2)L, and $L = k_1\sum_{l=1}^{T-2} l + k_2\sum_{h=1}^{T} h$ is the number of instruments per each instant of time;

- finally the one step GMM consistent estimator is

(13) $\underline{\hat{\beta}} = \left\{\underline{\Delta H'}_t \underline{Z}\left[\underline{Z'}\left(I_N \otimes \underline{V}_i\right)\underline{Z}\right]^{-1}\underline{Z'\Delta H}_t\right\}^{-1}\underline{\Delta H'}_t \underline{Z}\left[\underline{Z'}\left(\underline{I}_N \otimes \underline{V}_i\right)Z\right]^{-1}\underline{Z'\Delta Y}_t$

with variance regression $E\left(\underline{Z'\Delta\varepsilon\Delta\varepsilon' Z}\right) = \sigma_\varepsilon^2 \underline{Z'}\left(\underline{I}_N \otimes \underline{V}_i\right)\underline{Z}$ and $\underline{H'}_t = \left(Y_{t-1}, \underline{X'}_t\right)$. Further, given that such an estimation method is not more than the GLS method applied to (7), the estimator (13) is also efficient and correct.

As for the logistic function we adopt a two stage estimation. In the first stage □ $_{MOB}$, □ $_{TEL}$, □ $_{CAB}$, in eq. (6) are estimated by regressing with OLS the maximum value over time of B for each country on the r.h.s. variables dated at 2002, which is the start-up year for mobile broadband. In such a way we avoid simultaneity problems and may refer the maximum value of the broadband penetration to the initial conditions of the net subscriptions, which is of interest. In the second stage we estimate □ and □ in eq. (5) with NLS.

5. Variables and data

Our panel is composed of 17 years (1996-2012) and 23 OECD countries: Australia, Austria, Belgium, Canada, South Korea, Denmark, Finland, France, Germany, Japan, Greece, Ireland, Iceland, Italy, Norway, New Zealand, The Netherlands, United Kingdom, Spain, United States, Sweden, Switzerland, Hungary. Variables are from OECD and ITU database. Table 1 shows the mean and the standard deviation for the variables used. Capital case characters indicate natural numbers and GDP is expressed in thousands of PPP euro currency at 2005 prices.

In table 1 we specify our variables as follows: GDP per worker (Y) in US dollars, percentage population of the broadband subscribers (B), share of population holding a 3^{rd} *level education* title and working as researcher, i.e. skilled human capital (HK), rate of variation of workforce (L), the ratio between gross fixed capital formation and GDP (S). For the instrumental logistic function, models the broadband diffusion as F^b(.) of subscribers over 100 persons of mobile networks (*MOB_NET*), of wired networks (*TEL_NET*) and of cable networks (*CAB_NET*).

Table 1. Descriptive statistics

		Y (1.0e+3$)	*B* (100prs.)	*HK* (%)	*L* (%)	*S* (%)	*TEL_NET* (100prs.)	*CAB_NET* (100prs.)	*MOB_NET* (100prs.)
Australia	Mean	50.11	14.76	0.96	1.54	25.97	48.80	2.15	31.12
	Std.dev.	3.96	9.30	0.14	0.34	1.75	4.41	1.64	31.12
Austria	Mean	48.02	15.05	0.27	0.31	22.59	45.82	15.38	85.40
	Std.dev.	3.95	6.70	0.07	0.39	1.36	4.38	3.74	43.17

Belgium	Mean	46.86	20.17	0.40	0.47	20.56	46.69	37.50	70.90
	Std.dev.	3.09	8.16	0.09	0.34	0.89	2.10	1.01	37.77
Canada	Mean	48.20	20.75	0.59	1.19	20.55	60.72	25.27	42.37
	Std.dev.	3.37	7.64	0.08	0.11	1.47	6.07	1.06	20.53
South Korea	Mean	29.36	26.92	0.62	1.64	30.12	51.58	23.55	67.08
	Std.dev.	4.89	5.41	0.11	1.07	2.69	4,98	5.99	30.10
Denmark	Mean	48.14	23.40	0.62	0.17	19.16	61.75	27.36	82.23
	Std.dev.	2.89	13.22	0.20	0.11	1.28	7.95	6,78	34.91
Finland	Mean	43.22	20.55	0.70	0.27	19.63	44.56	18.48	91.21
	Std.dev.	5.14	10.00	0.19	0.12	0.93	11.74	1.56	36.04
France	Mean	45.05	16.33	0.66	0.55	18.89	56.74	5.06	62.06
	Std.dev.	2.58	11.72	0.04	0.20	1.26	0.89	0.88	31.65
Germany	Mean	46.25	15.78	0.32	-0.21	19.13	61.05	24.04	74.96
	Std.dev.	3.16	11.25	0.09	0.33	1.71	4.59	1.85	43.23
Japan	Mean	43.90	16.56	0.50	-0.51	23.67	45.35	14.63	64.45
	Std.dev.	2.91	8.23	0.02	0.30	2.34	6.15	3.30	22.74
Greece	Mean	33.03	6.87	0.18	0.34	21.63	51.56	6.85	72.61
	Std.dev.	4.57	7.64	0.20	0.25	2.37	3.97	5.23	39.34
Ireland	Mean	50.46	10.22	0.85	1.76	21.78	47.66	14.16	76.65
	Std.dev.	7.26	8.76	0.14	1.05	3.93	3.76	2.07	37.22
Iceland	Mean	47.98	21.70	0.79	1.48	22.18	63.88	1.07	81.09
	Std.dev.	4.52	11.44	0.26	1.35	5.57	3.41	0.86	31.18
Italy	Mean	41.05	11.20	0.44	0.12	20.29	43.28	6.42	96.03
	Std.dev.	2.00	7.93	0.14	0.42	0.83	4.46	15.20	48.28
Norway	Mean	68.84	20.12	0.67	0.97	20.22	48.33	20.54	83.01
	Std.dev.	3.80	13.16	0.07	0.28	2.12	8.07	4.93	28.26
New Zealand	Mean	36.03	11.20	0.87	1.24	21.38	44.62	0.34	66.22
	Std.dev.	2.61	9.32	0.10	0.57	1.51	2.53	0.26	35.11
The Netherlands	Mean	50.37	23.50	0.61	0.36	20.36	50.73	38.52	77.10
	Std.dev.	4.03	13.41	0.12	0.18	1.56	6.51	0.72	40.11
United Kingdom	Mean	47.04	16.41	0.78	0.56	16.69	56.44	8.79	83.81
	Std.dev.	3.64	11.84	0.10	0.50	0.82	1.97	7.05	41.55

Spain	Mean	37.71	13.28	0.50	1.09	25.97	42.84	2.56	73.99
	Std.dev.	3.13	7.41	0.04	0.70	3.12	2.00	2.76	38.38
United States	Mean	60.42	16.44	0.70	1.13	18.39	60.12	23.28	55.72
	Std.dev.	3.65	8.41	0.06	0.27	1.59	6.62	0.54	25.86
Sweden	Mean	47.09	20.26	0.51	0.58	17.70	62.89	19.81	84.01
	Std.dev.	4.46	10.84	0.08	0.25	1.16	5.33	8.18	29.26
Switzerland	Mean	51.83	21.46	0.43	0.77	21.68	68.05	36.61	76.18
	Std.dev.	2.53	13.02	0.09	0.36	0.98	5.09	1.36	38.20
Hungary	Mean	22.21	9.38	0.58	-0.12	22.26	33.16	15.67	67.37
	Std.dev.	3.04	7.21	0.07	0.09	1.54	3.24	6.90	44.30

Given the importance of the dynamic catching up pattern between BB and GDP, in order to test the relevance of technological ICT endowment for each country, we structured a leader-follower (*LF*) dummy variable according to ITU – ICT Development Index (IDI). We assume leaders (U.S., South Korea, Denmark, Finland, France, Japan, Iceland, Norway, Netherlands, Sweden) by being above the mean of IDI index value of our population.
Moreover, given the specific GDP fluctuations registered in the years of economic crisis, we tested the existence of a structural break during (2007-2008-2009)[4] by introducing a 'crisis' dummy variable (D_c).

6. Estimation results

In dealing with output growth and ICT infrastructure our results intend to show how the adjustment process is relevant.
As said, for comparability reasons with the approaches used in the literature and based on the estimation of an equilibrium relationship and above all in order to test the major generality of our approach, we start our estimations by adapting our disequilibrium approach ADMA, including the number of years from the beginning of broadband penetration in the countries (T^B) and without the effects of the crisis and the catching-up by D_c and *LF* respectively. We do not include the country specific effect of initial year GDP per capita of broadband introduction (y_0), because the convergence process is just explicitly considered in the ADMA specification[5].
As mentioned above, T^B and y_0 are variables not included in the steady state Mankiw model and, as a consequence, their usefulness in the estimation is to disentangle from the data the information concerning the long run condition form the actual observed of short run.
To begin with, in Table 1, we present two estimates of the equilibrium model. The first one EMA (LSDV-FD) is conducted by differentiating all the variables. Broadband penetration rate (*B*) was lagged to compare the contribution of the past and present rate penetration. The second one, ADMA, is the GMM Arellano Bond estimator (AB) that accounts for the adjustment of output. In this way we are able to cope with the time required for the adoption capacity of new technologies to be completely exerted on growth.

[4] The reason that led the identification of the years is linked to the decision to try to catch the multiform effects on GDP during the initial financial crisis and the real economy crisis.
[5] We account for specific country effects by considering random effects.

This has the advantage of accounting also for possible nonlinearities in the model, which usually occurs when the effects of innovations on output goes to completion.

Table 2

EMA			ADMA (Model 1)		
LSDV-FD, Dependent variable: Δlog-GDP percapita			**GMM-AB,** Dependent variable: log-GDP percapita		
regressors	Parameters	Coef.	regressors	Parameters	Coef.
-	-	-	log-GDP percapita (L1)	$\alpha_{y\text{-}1}$	0.64843*
	-	-		Std.Err.	0.06643
BB penetration rate	α_b	0.40204**	BB penetration rate	α_b	0.19632*
	Std.Err.	0.08970		Std.Err.	0.05816
BB penetration rate (L1)	$\alpha_{b\text{-}1}$	-0.35166**	-	-	-
	Std.Err.	0.09313		-	-
ΔFixed capital formation)	α_k	0.17991**	Fixed capital formation)	α_k	0.15002*
	Std.Err.	0.02533		Std.Err.	0.02088
ΔHuman capital	α_{hk}	0.04087**	Human capital	α_{hk}	0.06309*
	Std.Err.	0.01629		Std.Err.	0.01324
ΔWorkforce growth rate	α_l	-0.47498	Workforce growth rate	α_l	-0.72936**
	Std.Err.	0.34629		Std.Err.	0.35091
Year since BB introduction	α_t	-0.00459**	Year since BB introduction	α_t	-0.0100*
	Std.Err.	0.00113		Std.Err.	0.00245
log-GDP (1996)	α_{96}	-0.02138**	log-GDP (1996)	α_{96}	-
	Std.Err.	0.00589		Std.Err.	-
Constant	α_0	0.09499**	Constant	α_0	1.94866*
	Std.Err.	0.02027		Std.Err.	0.25767
Speed of adj	-		Speed of adj	0.352	
Mean time lag	-		Mean time lag	2.841	

*Significance level at 1%, **Significance level at 5%

The variables of both approaches (EMA and ADMA) are quite realistic since almost all significant and with the same signs. The ADMA, however, shows a more robust statistical significance results in all the determinants. Capital formation has a positive impact together with skilled human capital. Normal workforce and the time variable since BB introduction, differently, exhibit a negative sign. The negative sign of standard workforce growth-rate can be explained by contrast to the positive effect of the skilled human capital determinant, which is to say that, in the presence of a productive structure more and more based on ICT asset, an increasing rate of growth of normal workforce does not suffice to raise output per worker, while the opposite applies for skilled workers. For what pertains the negative sign of the time variable, "years since broadband introduction", its inclusion, in a first difference (EMA approach) and lagged estimations (ADMA approach), is to be interpreted as a quadratic term. In the former case, this means that we subtract a decreasing term, that evolves at decreasing rates, from the broadband coefficient effect on per capita GDP, given the time that is necessary for broadband deployment in order to cope with the delay in adopting the necessary broadband equipment and services in the productive sector. Differently, in the latter case, this issue has to be taken into account in the adjustment term. From an economic point of view this means that its interpretation is to be referred to the exogenous events. Therefore, we reckon that the negative sign of the time variable (years since broadband penetration) shows that the mentioned deployment effects need to be addressed with more care. In particular, we deem that the role of such a variable is to represent for the EMA approach all the nonlinearities, both exogenous and endogenous, while in ADMA only the exogenous ones.[6] In other terms, in our case the nonlinear endogeneity is captured by the adjustment process while the time variable picks, as better later specified, the (contingent) nonlinearity induced by the time of crisis. As a proof of this statement, we tested this conjecture by excluding the time variable under question in both EMA and ADMA approaches, obtaining in the EMA case a non significant estimation while our ADMA still performed highly significantly. Further, as anticipated above we deepened on the nonlinear exogenous effects obtained with ADMA of Table 2 substituting the trend variable with a dummy crisis variable capable to pick, again significantly, such exogenous factors on GDP. Since also this last refinement did not lead to a positive result in the EMA we definitely abandoned the first difference "traditional" equilibrium approach.

This provides a first empirical evidence that an adjustment process towards a long run equilibrium is at work. Specifically, with the EMA approach we can reliably asses only on the short run relationships and only by chance might capture long run interactions. Moreover, as afore mentioned, considering an adjustment approach allows to take into account in a proper way for possible endogenous - and stochastic - nonlinearities induced by the deployment of broadband penetration rate over time (Jamison and Holt, 2009).

Nevertheless, the two approaches provided similar overall estimates, apart from broadband penetration which, at a first sight, is much smaller in the ADMA case rather than in the EMA. However this first interpretation is misleading, since the opposite is true once we consider the effect of the lagged term in the AB estimator. This brings about a rise in such a coefficient at around 0.55. Therefore, given overall considerations, our strategy of analysis is to focus on the ADMA approach by distinguishing the short run from the long run.

As for nonlinearities in the growth path of our dependent variable, they emerge for first in the adjustment scheme of the Arellano-Bond method and for second in the peculiarities of our core variable broadband penetration rate. The former point gathers the aspects of time adoption of new technologies in the productive sector while the latter accounts for the consequences on the growth path of the time evolution in the broadband deployment.

[6] The negative effect for workforce has been found also in Maggi (2014) where a decreasing role for growth of the normal workforce is detected in favor to the skilled one, further an exogenous nonlinear trend is detected as well.

The other variables themselves account for nonlinearities with more traditional effects such as those of investments and labor. Both in the EMA and in ADMA we treat correctly the problem of nonlinearity by lagging or differentiating the variables involved while in the previous literature such step is skipped (Jamison and Holt, 2009), or in other cases is addressed to solve other problems such as the endogeneity (Czernich et al., 2011). On this second point we observe that, either we believe that the sample size allows to obtain stationary data after differencing, and in such a case differencing means also eliminating the endogeneity problem, or, if we do not believe it, we do need to find instruments (IV) but, for coherence with the differenced dependent variable, all nonlinear instrumental variables need to be differenced in any case in order to avoid biased estimates arising from spurious correlations[7].

We conclude this digression on the comparison with previous results by suggesting the ADMA (GMM-AB) method, in that by construction recurs to instruments (lagged or strictly exogenous variables), deals with endogeneity, considers the adjustment process (dynamic estimation) and (stochastic) nonlinearities by differentiating in the estimation phase. Moreover, it allows to consider any country random effect.

We proceed by further qualifying our estimation towards (1)-(3) strategy. The first step we make is to model broadband penetration as a logistic function in order to capture the endowment effect on growth deriving from the country specification of the broadband infrastructure and, in particular, including besides fixed and cable lines also the mobile connections (given the gradual fix-mobile convergence process of the electronic communication markets).

Table 3. Two-stage logistic IV model (countries: 23, years: 1996-2012)

Stage 1: Maximum BB level – OLS estimates	Coef.	Std.Err.
Fixed lines subs. x 100 inhab.s	0.3875943*	0.0523125
Cable lines subs. x 100 inhab.s	0.1811622*	0.0701239
Mobile lines subs. x 100 inhab.s	0.0537567**	0.0308767
Stage 2: Logistic curve fitting-NLS estimates		
Parameter δ	0.5954863*	0.0321067
R2=0.9835		

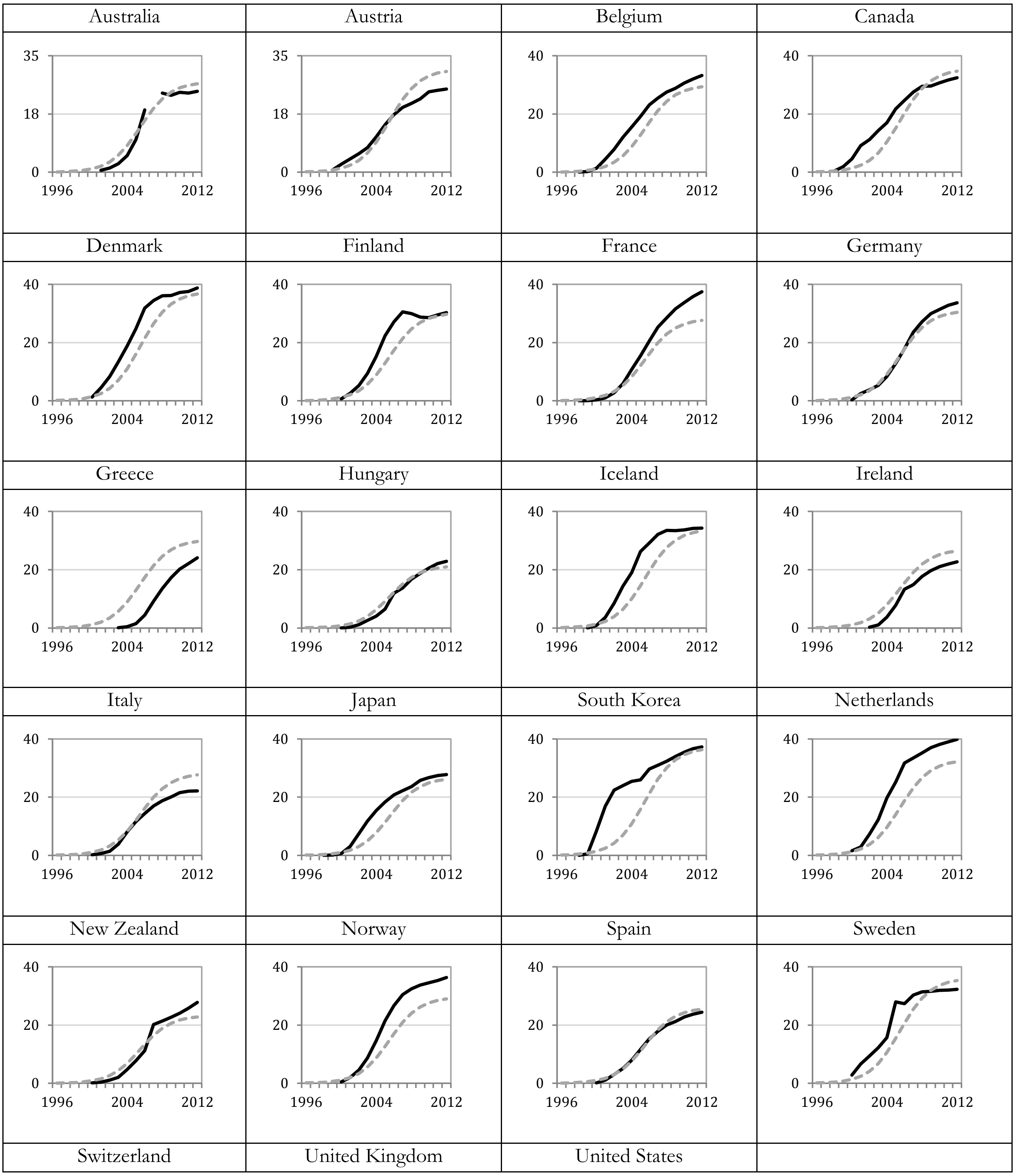
*Significance level at 1%, **Significance level at 5%

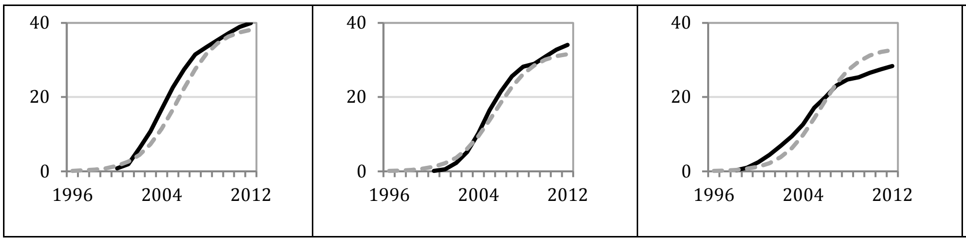
Results obtained in the second stage of the estimation procedure (see Table 3) show that the approximate average growth rate at any time step had been estimated around 59%. Even if the value is averaged both on the time and cross-sectional scale, looking at the data this result can be viewed as a consequence of the heterogeneity within the OECD countries, given regulatory and economic variables. In particular, according with Bouckaert et al. (2010), differences in BB demand and different types of competition dynamic, reflect distinct regulatory choices implemented by decision-makers. This is mainly a justification of the deep distance observed in the rate of growth before the point of diminishing returns, which is clearly identifiable with the year 2005 (Cznernich et al., 2011).

[7] In other words, the large sample stationarity of the differenced variables implies also cointegration and preserves from endogeneity other than from nonlinearity (in this case after differencing), in small or medium sample differencing allows only to deal with nonlinearity, if theoretically we have this information, and preserves only from spurious regression, but not from endogeneity.

The extension of instruments including mobile lines found a statistical justification at 10% confidence level. Fixed telephone lines still remain the main determinant of global maximum that can be reached by broadband users in each country. This can be reasonably due to the fact that mobile devices easily let a single user to "potentially" handle a multiple number of access available. Thus, mobile services are weakly associated with the characteristic of reaching a "saturation" level of subscribers. Conversely, telephone and cable lines are subject to a closer condition of saturation relation between user and service. Thus, it reasonably plays as a more powerful determinant of a steady saturation level of subscribers.

Figure 1. Actual (black) and fitted-logistic (grey-dashed) BB penetration rate





From this stage of analysis, it can be possible to conclude that broadband penetration rates during the period 2007-2012, which are the last years observed, experienced a faster growth with respect to how could be predicted with the available data. That can be likely attributed to an increased intensity of the aforementioned network effect. For both stages, the R-squared statistic reveals a very high goodness of fit of the logistic curve to the data. That can be visually appraised in Figure 1, where actual and fitted values for BB diffusion rate are plotted and compared. Of course the logistic representation underestimates the performance of leading countries, as South Korea and virtuous countries in Northern Europe (Netherlands, Denmark and Finland). Exactly the opposite is the case of Greece and Ireland, for which the deployment of BB penetration rate has been overestimated.

After having estimated broadband penetration rate through the logistic stage, in order to capture country specific initial endowment, we proceed to the third and final stage by estimating our final model specification as in eq. (3); overall results are presented in Table 4.

Table 4

ADMA **Dependent variable log-GDP percapita**		**Model 2**	**Model 3**
Regressors	**Parameters**	**Coef.**	**Coef.**
log-GDP percapita (L1)	α_{y-1}	0.79044*	0.76788*
	Std.Err.	0.02800	0.02874
BB penetration rate	α_b	0.06196**	0.0550**
	Std.Err.	0.02956	0.02961
Fixed capital formation	α_k	0.10469*	0.09714*
	Std.Err.	0.01698	0.01681
Human capital	α_{hk}	0.02123**	0.02220**
	Std.Err.	0.00982	0.00966
Workforce growth rate	α_l	-0.36991	-0.31867
	Std.Err.	0.29624	0.29116
Structural break (2007, 2008 and 2009)	α_{Dc}	-0.03460*	-0.03070*
	Std.Err.	0.00359	0.00387
Leader/follower dummy*	α_{LF}	-	0.11183**

	Std.Err.	-	0.05357
Constant	α_0	1.09016*	1.01669*
	Std.Err.	0.12900	0.13489
Speed of adj.		0.21	0.23
Mean time lag		4.762	4.348

In the third stage of our econometric approach we specify our final models 2 and 3. Table 4 reports the results from the estimation of the relationship between broadband penetration rate and GDP per capita after controlling for fixed capital formation, workforce growth rate, human capital (third level education and researchers) and our dummies concerning the economic financial crisis and the leader/follower innovation country position (the latter, only in the case of Model 3). In particular, the inclusion in models *2)* and *3)* of the dummies for the structural break of the financial crisis revealed to be in contrast with the trend variable considered in Model 1, and implicitly with the variable years since broadband introduction. As said above, such a variable can pick all the exogenous effect in the ADMA specification, and so also financial crisis effect, which now we want to highlight with greater evidence in models *2)* and *3)*. However, as expected, the lagged term slightly rises because the substituted variable, i.e. the trend, covers the major part of the observed period, so that in models *2)* and *3)* the lagged term account also for the dynamics not considered by the new dummies. Nevertheless, the coefficient of the broadband penetration rate is undervalued in these final models, which means that controlling for the period of the financial crisis reduces the role of the new technologies in favor of the more traditional resources for growth. As a confirmation of that, we note that, at least in the long run, Human capital is slighter undervalued in models 2) and 3) and, conversely, Fixed capital and Workforce growth rate rise their positive impact. In order to account for all these effects, together with the one emerging from the dynamic expressed by the lagged variable, we show in Table 5 the long run parameters, the mean time lags and the speeds of adjustment.

Table 5. Long run parameters

dependent variable	regressors	Coef. Mod. 1	Coef. Mod. 2	Coef. Mod. 3
Dependent: log-GDP percapita	BB penetration rate	0.558409	0.295667	0.224108
Dependent: log-GDP percapita	Fixed capital formation	0.426714	0.499571	0.41849
Dependent: log-GDP percapita	Human capital	0.179452	0.101308	0.09564
Dependent: log-GDP percapita	Year since BB introduction	-0.02648	-	-
Dependent: log-GDP percapita	Workforce growth rate	-2.07458	-1.76517	-1.37287
Dependent: log-GDP percapita	Leader/follower dummy	-	-	0.481777

Dependent: log-GDP percapita	Structural breaks (2007, 2008 and 2009)	-	-0.16511	-0.13226
Dependent: log-GDP percapita	Constant	5.542737	5.202138	4.380019
Speed of adj.	-	0.35157	0.20956	0.23212
Mean time lag (years)	-	2.844384	4.771903	4.308116

From Table 5 we can check that accounting properly for the period of financial crisis rises the mean time lag and consequently the period of adjustment. This is because the necessities of the real sector - i.e., new investments – have now a bigger impact, which imply a longer process of adjustment.

7. Policy implications

In this section we expound some of the possible policy implications deriving from the estimates obtained. We start by deriving the long run parameters, the speeds of adjustment and the mean time lags of the models chosen. In Table 5 we may take note of the amplified marginal effects of the coefficients estimated but, to be effective, we need to go beyond such a finding and qualify more explicitly the amount of output per capita obtainable and the time requested for such effects to be observable.

From tables 5, 4 and 3 we find the impact of a change in the broadband penetration on the GDP per capita for the OECD countries considered in the long and in the short run. However, since these are rather vague concepts we also compute the effect within the mean time lag, which is the amount of time expected to exert a relevant effect on the dependent variable following a change in the independent one. More specifically, this period is given by 2.84, 4.78 and 4.3 years, respectively for the first, second and third model estimated, which corresponds to what is commonly considered as the medium run. We now show that "relevant" means about the 63% of the discrepancy between the actual and the target value, that is in our case the increase in the broadband penetration (*BB*). In fact, by writing in a more compact form the expression (3)

(13) $\Delta y_{it} = \delta\left(y_{it}^{ss} - y_{it-1} \right)$

and making use of the suitable change of variable $s=t-\tau$, we may write (13) in terms of its continuous time equivalent form exponential lag distribution[8]

(14) $y_{it} = \int_{0}^{+\infty} \delta e^{-\delta\tau} y_{t-\tau}^{ss} d\tau = \int_{-\infty}^{t} \delta e^{-\delta(t-s)} y_s^{ss} ds$

from which, in order to discern how quantitatively relevant is the effect on which we are investigating within the mean time lag, we impose $\theta = 1/\delta$ and obtain

[8] The exponential lag distribution (14) is the continuous counterpart of the discrete development of (13) in terms of geometric lag distribution, or Koyck distributed lag equation, with $\delta e^{-\delta\tau}$ being the exponential distribution (see Kenkel, 1974).

(15) $\Delta YD_{it} = \alpha_b \Delta BB \int_{t-\theta}^{t} \delta e^{-\delta(t-s)} ds = \alpha_b \Delta BB \int_{0}^{\theta} \delta e^{-\delta\tau} d\tau = \alpha_b \Delta BB \left[-e^{-\delta\tau} \right]_0^{\theta} \cong 0.632 \alpha_b \Delta BB$

where α_b is the long term, or steady state, parameter of *BB* in Table 5. We adopted the symbol *BB* in the above formulation instead of F_b used in expressions (1)-(3) because the latter has been adopted cope with the indirect estimation of Section 6, while here we are interested in applying the estimated coefficients to the data.

This refinement represents, with compare to existing literature, the most relevant implication of our estimation strategy. The ADMA approach besides rigorously taking into account the adjustment process towards the equilibrium and coping with non linearity, indeed allows to measure in real terms and for each country in the short, medium and long run – interpreting the speed of adjustment – the impact on GDP per capita of a percentage increase of *BB*.

In the following Table 6, thus, we calculate the marginal effect on the per capita GDP of a 1% change in the average level of *BB* as reported in Table 1.

Table 6. Projection of the real short (2013) and long run (mean time lag) impact on per capita GDP from an increase in 2013 of 1% BB. Values expressed in units of US dollars.

		Coef. Mod. 1	**Coef. Mod. 2**	**Coef. Mod. 3**
Australia	Short run	1098.43	346.67	291.06
	long run	3124.36	1654.29	1253.91
	Mean time lag period	1968.34	1042.20	789.96
Austria	Short run	1105.10	348.78	292.82
	long run	3143.33	1664.33	1261.52
	Mean time lag period	1980.30	1048.53	794.76
Belgium	Short run	1340.20	422.98	355.12
	long run	3812.06	2018.41	1529.90
	Mean time lag period	2401.60	1271.60	963.84
Canada	Short run	1526.25	481.70	404.42
	long run	4341.24	2298.60	1742.28
	Mean time lag period	2734.98	1448.12	1097.64
South Korea	Short run	1639.15	517.33	434.34
	long run	4662.38	2468.64	1871.17
	Mean time lag period	2937.30	1555.24	1178.84
Denmark	Short run	1514.90	478.11	401.41
	long run	4308.96	2281.51	1729.33
	Mean time lag period	2714.65	1437.35	1089.48

Finland	Short run	1297.65	409.55	343.85
	long run	3691.02	1954.33	1481.33
	Mean time lag period	2325.34	1231.23	933.24
France	Short run	996.46	314.49	264.04
	long run	2834.32	1500.72	1137.51
	Mean time lag period	1785.62	945.45	716.63
Germany	Short run	1106.68	349.28	293.24
	long run	3147.84	1666.72	1263.33
	Mean time lag period	1983.14	1050.03	795.90
Japan	Short run	1035.16	326.70	274.29
	long run	2944.38	1558.99	1181.68
	Mean time lag period	1854.96	982.17	744.46
Greece	Short run	2697.44	851.33	714.75
	long run	7672.55	4062.47	3079.25
	Mean time lag period	4833.70	2559.36	1939.93
Ireland	Short run	723.83	228.45	191.80
	long run	2058.85	1090.12	826.29
	Mean time lag period	1297.08	686.78	520.56
Iceland	Short run	1474.32	465.31	390.66
	long run	4193.54	2220.40	1683.01
	Mean time lag period	2641.93	1398.85	1060.29
Italy	Short run	591.92	186.81	156.84
	long run	1683.64	891.46	675.70
	Mean time lag period	1060.70	561.62	425.69
Norway	Short run	1866.21	588.99	494.50
	long run	5308.21	2810.60	2130.36
	Mean time lag period	3344.17	1770.68	1342.13
New Zealand	Short run	591.51	186.68	156.73
	long run	1682.47	890.84	675.23
	Mean time lag period	1059.96	561.23	425.40

The Netherlands	Short run	1776.10	560.55	470.62
	long run	5051.92	2674.89	2027.50
	Mean time lag period	3182.71	1685.18	1277.33
United Kingdom	Short run	1058.14	333.96	280.38
	long run	3009.77	1593.61	1207.92
	Mean time lag period	1896.15	1003.98	760.99
Spain	Short run	689.69	217.67	182.75
	long run	1961.76	1038.71	787.32
	Mean time lag period	1235.91	654.39	496.01
United States	Short run	1473.85	465.16	390.53
	long run	4192.20	2219.69	1682.47
	Mean time lag period	2641.08	1398.40	1059.95
Sweden	Short run	1399.98	441.84	370.96
	long run	3982.08	2108.44	1598.14
	Mean time lag period	2508.71	1328.31	1006.83
Switzerland	Short run	1682.84	531.12	445.91
	long run	4786.65	2534.44	1921.04
	Mean time lag period	3015.59	1596.70	1210.26
Hungary	Short run	326.81	103.14	86.60
	long run	929.57	492.19	373.07
	Mean time lag period	585.63	310.08	235.03

As one may easily check and as expected in Table 6, marginal effect on the output per capita within the mean time lag period is greater than the one exerted in the short run. In particular, at the short run (one year in our case) only the 56%, 33% and 37% of the relevant effect of the medium run is evaluable, for the three models, respectively. This confirms that the gains from the new technology in terms of per capita output takes time to be observable and that, even if not yet exhausted, the medium run is a more reliable term of reference. Moreover, we underline the change in the impact of the broadband penetration when accounting for the crisis, which, though still relevant, is sensibly reduced for all countries.

8. Closing remarks

A bulk of literature regarding the impact of broadband infrastructures on economic growth shared the common view about the consistency of a positive effect impact. In the groove of such empirical works, our paper deepens the analysis on the effects that broadband diffusion displays on gross domestic product (per capita), on the base of a panel composed by a sample of n. 23 OECD countries over 17

years (1996-2012). Overall, the all results confirm that broadband diffusion (BB) is both statistically significant and positively correlated with growth in real GDP per capita. This result is robust even after controlling for fixed capital formation, human capital, workforce growth rate, years since BB introduction, national ability to innovate (leader/follower) and structural breaks (crisis). Our results also suggest that broadband diffusion has diminishing returns, that is to say that countries that are in an earlier stage of diffusion are able to gain more from promoting BB. In other terms, given the ability to foster economic growth, there are high incentives for public policy interventions (on both the side of demand and supply) oriented to enhance BB diffusion.
In achieving this results we implemented a dynamic growth model (Adjustment Equilibrium Model Approach – ADMA) which considers the adjustment process towards the equilibrium based on instrumental variables. This allows for both testing and assessing the long-run or short run relation of the estimated equation and overtake the endogeneity problem. In considering that an adjustment process is in force, moreover, we can cope also with the nonlinear effects of BB on GDP taking into account the time adaption needed to implement new technologies (Holt and Jamison, 2009).

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