MAGKS

Joint Discussion Paper Series in Economics

by the Universities of

Aachen · Gießen · Göttingen
Kassel · Marburg · Siegen

ISSN 1867-3678

No. 34-2016

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Low latency internet and economic growth: A simultaneous approach

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Low Latency Internet and Economic Growth: A Simultaneous Approach*

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August 2016

Given the quality of the available data on Internet access across several countries, it is necessary to evaluate alternative measures to assess the effect of Internet access on economic outcomes.

The research at hand builds up on an earlier paper, which introduced a novel measure of Internet quality. A logical consequence has been to introduce the new indicator (average latency for a country) into established models of economic growth. The data used in this analysis spans the period from 2008 to 2014 and covers 155 countries. The findings largely confirm previous results, that Internet access is beneficial to economic growth and emphasize the appropriateness of technical measures of Internet quality for economic analysis. Apart from providing insight into the quality dimension these measures do not rely on survey data, but can be obtained directly requiring only a low level of investment, making the data collection process viable even for smaller institutions.

JEL: O47, O57, L96

Keywords: Economic Growth, Simultaneous Equations, Internet, Latency

*I am grateful to Steffen Viete (ZEW) for his valuable comments and to Les Cottrell at Stanford for providing the latency data. In addition I am grateful for a DAAD travel grant which allowed me to attend the TPRC conference in Arlington, VA, USA..

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1. Introduction

The reliance on Internet connectivity has become common place in most industrialized economies and there is empirical evidence that broadband access contributes to economic growth. Unfortunately, the empirical studies in this area suffer from limited data availability to assess long-run growth effects and usually cover only small sets of countries. The aim of this study is to introduce a novel measure for internet quality and show that it can be used in a conventional growth model. The latency of an internet connection can be measured directly and one does not rely on intergovernmental agencies for collecting the data.

Apart from the lack of availability some existing measures also have conceptual problems. Hence, it becomes crucial to discuss the operationalization of internet usage, availability or quality when interpreting results in a context of economic growth or the digital divide. For example, the penetration rate, i.e. the share of population using the technology, is easily available from the World Bank and therefore widely used (Czernich et al. 2011; Koutroumpis 2009). Comparing the penetration rate across countries is dangerous as the survey methodology differs across countries and it neglects any information about the quality and frequency of internet access. Moreover, the fact that the ratio is bound by 0 and 1, one may falsely "discover" that the digital divide is closing, as some (in particular Scandinavian) countries have reached a penetration rate of close to the hundred percent bound. Consequently, any increase in the penetration rate in a developing country will result in a smaller "divide" between the industrialized and the developing country, despite an increasing divide in qualitative terms.

Consequently, new measures are needed to quantify the phenomenon and provide a sound foundation for the discussion of internet and growth, as well as the extend of the digital divide. One possibility is the use internet bandwidth per user (Rohman and Bohlin 2012). This provides information to one aspect of quality, but it remains difficult to estimate. Hence, I propose the use of latency data, which can be directly measured from every computer on the internet. Therefore, it is not subject to the same difficulties when aggregating data from country specific survey sources. Bandwidth (usually referred to when discussing internet speed) and latency are two concepts that are best explained jointly. Bandwidth is the amount of information which can be transported at a single point in time between two points. In contrast latency is the actual time of transportation between two points. A shipping container full of hard disks is an illustrative example of a very high bandwidth connection between two ports. However, transporting the data in a truck from Melbourne to Atlanta may well take days on a cargo vessel, before the first bit of information arrives at the destination. In contrast, transmitting morse codes via ham radio covers the distance within milliseconds but only providing enough bandwidth for a few characters per minute. Modern broadband communication combines a low latency with a high bandwidth, with slight differences depending on the technology used.

After Lüdering (2015) discussed the suitability of latency as a proxy for Internet quality, this paper tries to assess the suitability of this indicator by introducing it into a growth model. Consequently, it contributes additional evidence on the causal relationship between Information and Communications Technology (ICT) infrastructure and economic growth by combining a dataset (Zennaro et al. 2006) which is novel to economics with the established methodology from Röller and Waverman (2001) and Koutroumpis (2009). The dataset used here does not cover quite as many countries as Lüdering (2015) but also contains a time dimension. The dataset used in the analysis spans a period of 6 years from 2008 to 2014.

The remainder is organized as follows. Section 2 provides a brief overview of the literature on the relationship between economic growth and ICT infrastructure. Subsequently, the data used in this paper is described in Section 3 while Section 4 elaborates on the empirical approach. The results are discussed in Section 5 and Section 6 closes with a conclusion.

2. Economic growth and telecommunication technology

In neoclassical growth models (Solow 1956; Swan 1956) technological progress is the sole driver of economic growth in the steady state. Endogenous growth models (Romer 1990) endogenized the creation of new, "non-rival" technology from human capital. The utilization of these new technologies eventually leads to economic growth. Hence, any mean, such as Internet access and economic integration that facilitates access to new technologies is growth enhancing.

The nature of ICT as a General-Purpose Technology implies that an investment in ICT capital leads to improvements in productivity across many fields of the economy leading to growth in total factor productivity. However, in order to realize the associated productivity gains complementary investements in other capital (e.g. knowledge) are required. These additional investments contribute to economic growth as Basu and Fernald (2007) show.

The empirical work on the relatonship between communication means and economic development dates back to Hardy (1980), who finds evidence that landline telephones are an important contributor to economic development. However, his results proved not to be robust to alterations in the sample of countries. More recent work by Röller and Waverman (2001) used an updated methodology that endogenized demand and supply for telecommunication. The authors find strong evidence for a link between telecommunication and economic growth. By differentiating between three levels of telecommunication infrastructure Röller and Waverman find evidence of positive network externalities. The necessary critical mass for increasing returns appears to be close to universal service. Sridhar and Sridhar (2007) refine the approach and specifically address the case of developing countries. Along these lines Lee, Levendis, and Gutierrez (2012) also conduct an empirical analysis of the impact of telecommunication infrastructure on economic growth in developing countries. They find that there is a particular large effect for mobile telecommunication on economic growth. This hints at the possibility of leap-frogging and skipping the costly investment into landline infrastructure.

Subsequent analysis have turned towards the relationship between economic growth and Internet. Using a simple linear estimation approach Qiang and Rossotto (2009) find a large effect of broadband Internet connectivity on economic development. Applying the more sophisticated simultaneous estimation approach by Röller and Waverman (2001) Koutroumpis (2009) manages to establishes a causal link between Internet usage and economic development using a panel of the EU-15 countries over the duration of three years. He finds significant returns to ICT investments in particular for countries with a high initial penetration rate (e.g. the Scandinavian countries). Czernich et al. (2011) use an intrumental variable approach to estimate the impact of broadband adoption on economic growth. In order to solve issues of endogeneity the authors construct a theoretical broadband penetration rate, which they employ in the estimation. A recent contribution by Clarke, Qiang, and Xu (2015) took a closer look on the effects of Internet usage on the level of the individual firm. They find a robust link between Internet use and labor productivity for firms of different sizes but in particular for small and medium enterprises.

3. Data

The data used in this analysis is compiled from a variety of sources. Details of the origin of specific variables is provided in Table 1. While most of the variables are standard and the data are taken from the specified sources, there are a few specificities which are illustrated in this section.

Table 1: Variables used in the analysis

Name	Description	Source
GDP	GDP	World Bank
GDPC	GDP per capita	World Bank
K	stock of capital	Penn World Tables and World Bank
L	size of labor force	World Bank
ICT	average round trip time	PingER
P	Broadband Price	ITU
EDU	spending on education (% of GDP)	World Bank
RD	R&D investment (% of GDP)	World Bank
Urban	Urban Population (%)	World Bank
ICTI	ICT Investment	ITU
InterPlatform	Herfindahl index for inter-platform competition	own calculation based on ITU data

It is a common issue in the empirical growth literature that one needs to calculate the stock of capital. In many cases, it is sufficient to revert to databases such as the Penn World Tables. However, the recent edition of the database does not cover the sample period in this article. As a workaround I calculate the capital stock for the analysis period using the initial capital stock from the Penn World Tables and add the investments available from the Worldbank, assuming a constant deprecation rate of 4.5% (based on Berlemann and Wesselhöft 2012) for all countries.[1] Ideally, one would deduct ICT capital from the general capital stock. However, the limited availability of data on ICT investments and the stock of ICT capital does not permit this. As the stock of ICT capital is small in contrast to general capital, the effects on the analysis should be negligible. If there was any effect, it would lead to an underestimation of the effect of ICT.

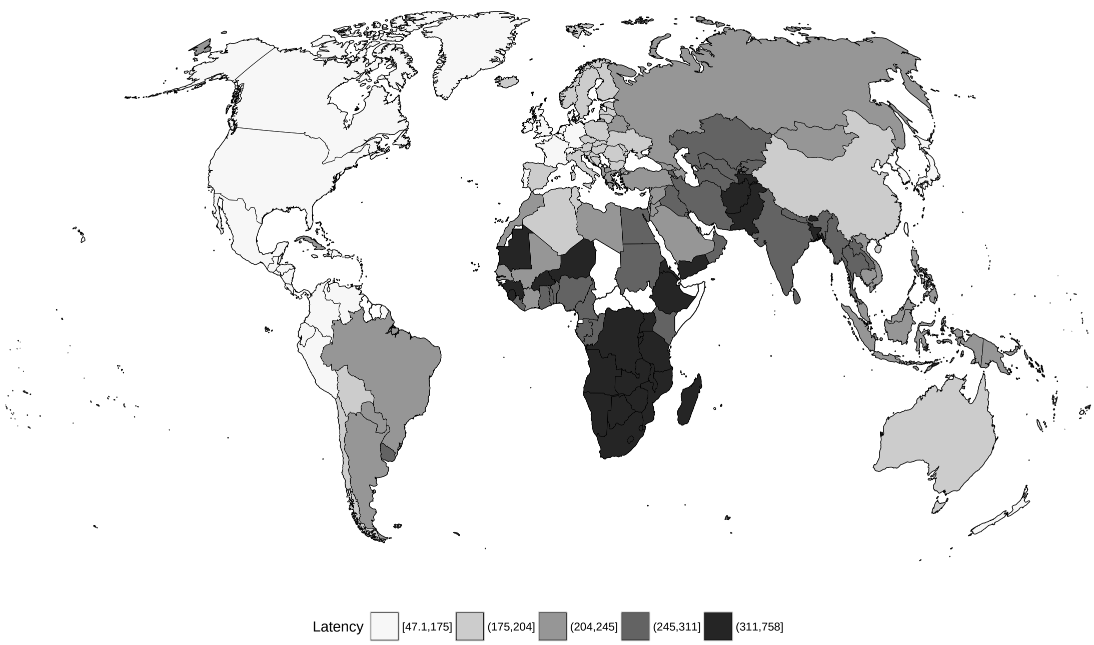
As a measure for Internet quality this paper uses latency data (specifically average round-trip-time). The data is provided by the PingER (Ping End-to-end Reporting) project (`http://www-iepm.slac.stanford.edu/pinger/`) run by SLAC National Accelerator Laboratory at Stanford University. An introduction to the PingER facility and dataset can be found in Zennaro et al. (2006). The *average round trip time* is the time that has passed between sending a

[1] The results appear to be not sensitive to the assumed value of the depreciation rate.

request to a remote server and receiving the answer at the monitoring server at Stanford University. This implies that lower values indicate a better Internet quality. In order to aid interpretation as Internet quality in the regression analysis the values are multiplied by -1 after taking the logarithms, consequently positive coefficients will imply positive influence of Internet quality.

The measurements are aggregated per country and year, as the data is collected for several nodes in a single country and at an hourly frequency. The resulting dataset is available for a large set of 165 countries (see Figure 1). Unfortunately these sites have been added to Pinger consecutively. For example, there is no data on Panama and the United Arab Emirates before 2015. Other shortcomings include that the split of "Serbia and Montenegro" has not been incorporated into the data to date. The countries completely missing from the dataset due to the lack of remote-sides include small countries like Suriname and Guyana, and the closed off or crises stricken countries Somalia, Chad, Central African Republic, South Sudan and North Korea.

Figure 1: Spatial Distribution of Average Round Trip Time in 2014



There is no data (in 2014 or not at all) available for countries colored white

Due to the absence of direct measures of telecommunication (e.g. number of companies providing Internet access), the level of competition between different technologies to access the Internet is used as a proxy for competition. The Herfindahl index for the inter-platform competition in the telecommunication market measures the concentration of the industry by summing up the market shares of each considered platform. Analogous to Koutroumpis (2009) for country i in year t it is given by:

$$\text{InterPlatform}_{it} = \sum_{1}^{n} \left(\frac{\text{Platform}_m}{\text{Total connections}} \right)^2 \tag{1}$$

The approach in the paper at hand, differs slightly in the scope. It includes data on all types of Internet connections where Koutroumpis (2009) is limited to broadband connections. While the primary focus lies on FTTH (Fiber optic cable to the home / to the building), DSL (Digital Subscriber Line) and (TV-) Cable in both cases, the "other" platform in this paper sums up all means of Internet connections in the ITU database which includes wireless (i.e. via wifi), satellite, dail-up and "other". Considering all means of Internet access should also be reflected by the used prices. Ideally one would use an aggregate price index of all access technologies. Due to reasons of data availability prices for broadband connectivity are used as proxy for general Internet pricing.

4. Empirical Analysis

Missing values in the dataset, in particular information on prices and investment into ICT infrastructure makes it necessary to apply imputation methods. For this exercise the *Amelia*[2] package for R is employed. After generating five imputed datasets the coefficient values are aggregated using Rubin's Rules (Rubin 1987). In addition one may also aggregate the R^2 values for regressions on multiple imputed datasets (Harel 2009). However, since the aim of instrumental regression lies in precise estimation of the effect of covariate x on dependent variable y when x is correlated with the error term, goodness to fit is in general not of interest. Moreover, in this case R^2 also lacks a natural interpretation and may also become negative. Nonetheless, R^2 is reported here by convention. While it is straight forward to perform multiple imputation on the dataset and estimate the system of equations the application of the aggregation rules remains largely untested for simultaneous estimation procedures.

[2] `https://cran.r-project.org/web/packages/Amelia/`

A lot of missing data is due to a small set of countries: Angola, Eritrea, Faroe Islands, Greenland, Liechtenstein, Myanmar, French Polynesia, Puerto Rico, San Marino, Syria contain a large amount of NA values. However, removing these countries before imputation does not have a large effect on the results.

The empirical approach of this analysis builds up on the simultaneous estimation approach originally developed by Röller and Waverman (2001) and later refined Koutroumpis (2009). By following the model by Koutroumpis (2009) as close as possible I attempt to make the results comparable and infer whether round trip time can be used as a proxy for Internet quality. The differences that exist between the analysis at hand and Koutroumpis (2009) are due to issues of data availability. Working with a larger sample of countries some information was not available in a consistent manner. Consequently, the model was slightly altered. For example Koutroumpis (2009) included a measure of regulation of the telecommunication industry. This measure has been omitted from the model in this paper as the data is not available for the countries and timespan used in the analysis.

The model relies on a classical aggregate production function where a country's economic output is determined given by capital and labor. The model is augmented with a measure of Internet quality, as an additional factor.

$$\text{GDP}_{it} = f(K_{it}, L_{it}, ICT_{it})$$

. K is the level of capital (not including ICT capital) L is the size of the labor force and ICT is ICT capital.

Again following Koutroumpis (2009) a micro model is used to endogenize the creation of ICT capital by modeling demand, supply and production equation of ICT capital.

The demand for Internet quality is given by

$$\text{ICT}_{it} = h(\text{GDPC}_{it}, \text{P}_{it}, \text{URB}_{it}, \text{EDU}_{it}, \text{RD}_{it})$$

stating that the Internet quality demanded depends on income per head, prices, the share of the population living in urban agglomerations and the expenditure on education and R&D.

The supply of Internet quality consists of the investments in ICT capital which is solely determined by prices and market structure

$$\text{ICTI}_{it} = g(P_{it}, \text{InterPlatform}_{it})$$

and the resulting improvement in quality (production function)

$$\Delta \mathrm{ICT}_{it} = k(\mathrm{ICTI}_{it})$$

. Using a log-linear approximation this model gives rise to the following system of equation:

$$\log(\mathrm{GDP}_{it}) = a_0 + a_1 \log \mathrm{K}_{it} + a_2 \log \mathrm{L}_{it} - a_3 \log \mathrm{ICT}_{it} + \varepsilon^1_{it} \quad (2)$$

$$\log(\mathrm{ICT}_{it}) = b_0 + b_1 \log \mathrm{GDPC}_{it} + b_2 \log \mathrm{P}_{it} + b_3 \mathrm{EDU}_{it} + b_4 \mathrm{URB}_i t + b_5 \mathrm{RD}_{it} + \varepsilon^2_{it} \quad (3)$$

$$\log(\mathrm{ICTI}_{it}) = c_0 + c_1 \log \mathrm{P}_{it} + c_2 \mathrm{InterPlatform}_{it} + \varepsilon^3_{it} \quad (4)$$

$$-\log\left(\frac{\mathrm{ICT}_{it}}{\mathrm{ICT}_{i,t-1}}\right) = d_0 + d_1 \log \mathrm{ICTI}_{it} + \varepsilon^4_{it} \quad (5)$$

5. Results

Following Koutroumpis (2009) the empirical model is estimated applying a three-stage-least-squares GMM approach. In addition two-stage estimates are provided. Both methods are used to jointly estimate a system of equations, the third step takes the interdependence of the error terms into account and provides more accurate coefficient estimates. The estimation results are in detail provided in Table 2. There is a strikingly huge positive significant effect of ICT quality on GDP. The size of the effect is huge over all specifications ranging from an increase of 0.45% to 2.5% in GDP for a 1% increase in Internet quality. The other coefficients are not central to this paper. The estimation of the equation system aims at providing a consistent estimate of the effect of ICT quality on GDP growth, rather than examining the specificities of demand and supply effects. Nonetheless, the coefficients largely have the expected signs. Demand is reduced by prices and increased by urbanization, education and R&D investments. Supply is reduced by a higher Herfindahl index (*i.e.* less inter-platform competition). The negative sign of price in the supply equation is a little bit surprising. Similarly, in the ICT production equation one would expect the investments in ICT effect to have a positive effect on the change in Internet quality.

Including dummy variables for each country and each year reduces the size of the coefficient of interest and leads to a loss of significance for many variables in the system. In particular urbanization education spending and research and development investments are likely time-invariant country specificities, which are completely captured by the included country specific effects. In addition,

Table 2: Statistical models

	(1) 2SLS	(2) 2SLS-fixed	(3) 3SLS	(4) 3SLS-fixed
Aggregate Production				
(Intercept)	19.903***		15.349***	
	(3.780)		(4.294)	
K	0.515***	0.030	0.655***	0.034
	(0.094)	(0.031)	(0.111)	(0.030)
L	0.326***	0.332**	0.169*	0.324**
	(0.074)	(0.172)	(0.106)	(0.169)
ICT	2.502***	0.477**	1.902***	0.449**
	(0.440)	(0.230)	(0.534)	(0.221)
Demand				
(Intercept)	−5.154***		−5.488***	
	(0.285)		(0.379)	
GDPC	0.008	−1.231	0.036	−4.810
	(0.028)	(22.069)	(0.034)	(23.580)
P	−0.307***	−1.118	−0.258***	−1.098
	(0.050)	(3.247)	(0.058)	(3.023)
URBAN	0.007***	0.013	0.006***	0.069
	(0.001)	(0.288)	(0.001)	(0.293)
EDU	0.017**	0.040	0.019***	0.044
	(0.010)	(0.174)	(0.006)	(0.160)
RD	0.109***	0.107	0.105***	0.054
	(0.021)	(0.379)	(0.034)	(0.358)
Supply				
(Intercept)	32.666***		32.815***	
	(2.376)		(2.330)	
P	−1.691**	−0.521	−1.809***	−0.475
	(0.755)	(0.491)	(0.720)	(0.430)
InterPlatform	−11.896**	0.627	−11.478**	1.133
	(6.699)	(1.793)	(6.444)	(1.473)
Infrastructure Production				
(Intercept)	0.184**		0.202**	
	(0.095)		(0.091)	
ICTI	−0.007*	0.447	−0.008**	0.657
	(0.005)	(0.547)	(0.005)	(0.675)
Adj. R^2				
Aggregate Production	0.750	0.996	0.838	0.997
Demand	0.397		0.435	
Supply		0.829		0.835
InfraProd				

$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$

K, L, ICT, GDPC, P, ICTI are log transformed

Model 2 and 4 include country and year dummies to control for specificities the depressed growth rates due to the global financial crises are to a large extent captured by the time fixed effects.

After having obtained an estimate for the coefficient one can address the question what the economic effect of improvements in ICT quality has been over the period of six years. The growth in ICT quality is approximated by the log differences, which is multiplied by the estimated coefficient.

$$\mathrm{GE} = [(\log \mathrm{ICT}_{2014} - \log \mathrm{ICT}_{2008}) \times (-\hat{a}_3) + 1]^{\frac{1}{6}} \tag{6}$$

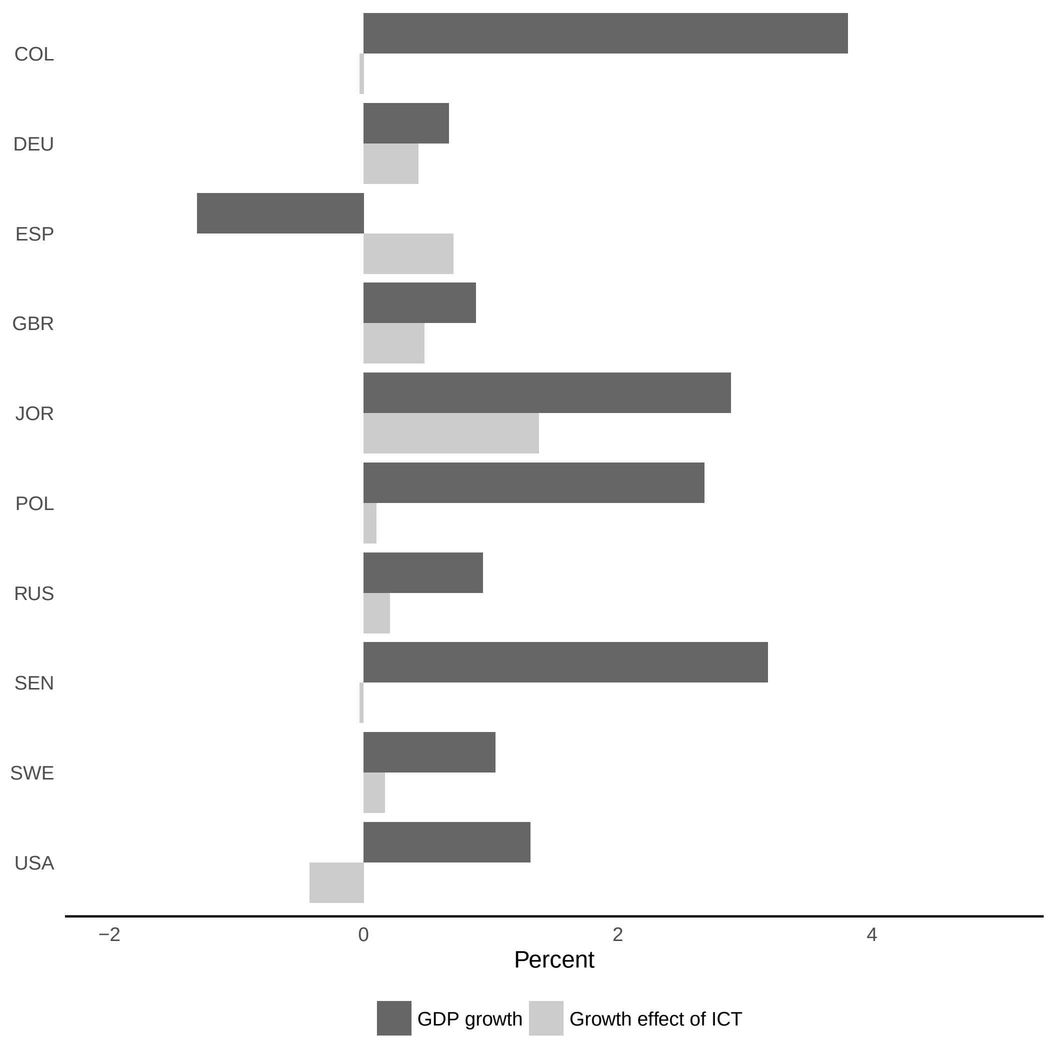
Figure 2 shows the average growth effects (GE) and countries GDP growth rate over the whole period for a subset of the included countries (The results for all countries can be found in Figure 4 in the appendix). Columbia had an growth rate of GDP of 3.8% annually, while the effect of improvements in ICT had a small negative effect. For the US the lack of improvements in ICT quality had an even stronger negative effect. This illustrates, that economic growth is a net-effect resulting from a variety of influences. For most countries growth contribution of ICT improvement and economic growth have the same sign: Germany, growing 0.67% annually, had a contribution of 0.43 percentage points from ICT improvements. However, in Spain there was a positive growth effect of 0.7% from ICT in spite of suffering from negative economic growth during the period, due to the European sovereign debt crises.

The reported effects are very large, in terms of elasticity of GDP with respect to Internet quality, but also in terms of the growth contribution of ICT. The effects reported here are of the same magnitude as reported by Koutroumpis (2009). For example, the research at hand finds a growth contribution of 0.7% of ICT for Spain, while Koutroumpis reports 0.39% for Spain[3]. Due to differences in methodology comparing the results of Czernich et al. (2011) is not as straight forward, as the authors examine the changes in GDP *per capita*. They find that a change of 1 percentage point in the broadband penetration rate leads to an increase of annual GDP per capita growth of 0.9 to 1.5 percentage points. Which is of the same magnitude as the median growth effect of 0.71% (mean: 1.57%) of Internet quality.

As outlined earlier the combination of simultaneous equation modeling with multiple imputation appears to be untested. In order to check the robustness of the results the approach is twofold. On the one hand, regression results for complete cases and, respectively a dataset generated by

[3] Unfortunatelly, Koutroumpis (2009) does not provide compound annual growth effects for more countries

Figure 2: Growth contribution of ICT



single imputation are provided in Table 5. In particular the single imputation case yields coefficients of very similar size as in the multiple imputation case. As expected, the standard errors are smaller when relying on single imputation for missing values. If one only considers the complete cases the number of observations is substantially reduced, leading to several differences. It is notable that the coefficient of interest to this analysis on ICT remains similar in size and significant at the 10% level. On the other hand, the stability of the estimation results is confined using a simulation method. The applied simulation procedure is outlined in greater detail in Appendix B. The results indicate that the application of multiple imputation reduces the variance of the estimated coefficient at the cost of a small bias.

6. Conclusion

The preceding analysis shows that the direct measure of latency can be used as a proxy of Internet quality. The estimation technique builds up on the methodology by Röller and Waverman (2001) and Koutroumpis (2009) to mitigate the potential for simultaneity.

Using latency as a proxy for ICT quality make it possible to obtain information on the infrastructure quality on a variety of countries without relying on data collected by a country's authorities. This increases the number of countries on which consistent information on Internet quality are available. Thus, the sample covers 155 countries compared to the subset of OECD countries usually used in previous papers.

The evidence from the analysis confirms the strong effect of ICT infrastructure on economic development established in Koutroumpis (2009) and Czernich et al. (2011). While these previous studies have established that Internet *usage* is an important factor for growth, my contributions finds that it is also the quality of the infrastructure that matters. This implies that despite a narrowing digital divide in terms of users, the qualitative dimension is also important.

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A. Additional Tables

Table 3: Summary Statistics

Variables	N	Mean	St. Dev.	Min	Max
GDP	1,082	24.396	2.069	19.999	30.325
K	936	26.230	1.932	22.080	31.441
L	1,071	15.409	1.563	12.007	20.508
ICT	933	−5.529	0.499	−7.582	−3.194
GDPC	1,082	8.239	1.611	4.989	11.356
P	986	3.330	0.932	−0.056	7.473
EDU	559	4.809	2.085	1.100	19.258
RD	473	1.057	1.025	0.013	4.387
URBAN	1,085	58.459	23.022	8.550	100.000
InterPlatform	465	0.557	0.161	0.226	1.000
ICTI	668	20.167	1.839	12.062	25.117

Note: Summary statistics calculated before imputation.
K, L, ICT, GDPC, P, ICTI are log transformed

Table 4: Countries in PingER dataset

Afghanistan	El Salvador	Liberia	Rwanda
Albania	Eritrea	Libya Arab Jamahiriya	San Marino
Algeria	Estonia	Liechtenstein	Saudi Arabia
Andorra	Ethiopia	Lithuania	Senegal
Angola	Faroe Islands	Luxembourg	Seychelles
Argentina	Finland	Macedonia	Sierra Leone
Armenia	France	Madagascar	Singapore
Australia	French Polynesia	Malawi	Slovak Republic
Austria	Gabon	Malaysia	Slovenia
Azerbaijan	Gambia	Maldives	Solomon Islands
Bahamas	Georgia	Mali	South Africa
Bahrain	Germany	Mauritania	Spain
Bangladesh	Ghana	Mauritius	Sri Lanka
Belarus	Greece	Mexico	Sudan
Belgium	Greenland	Moldova	Swaziland
Benin	Guatemala	Mongolia	Sweden
Bhutan	Guinea	Morocco	Switzerland
Bolivia	Haiti	Mozambique	Syria
Bosnia Herzegovina	Honduras	Myanmar	Tajikistan
Botswana	Hong Kong	Namibia	Tanzania
Brazil	Hungary	Nepal	Thailand
Brunei	Iceland	Netherlands	Timor-Leste
Bulgaria	India	New Zealand	Togo
Burkina Faso	Indonesia	Nicaragua	Trinidad and Tobago
Burundi	Iran	Niger	Tunisia
Cambodia	Iraq	Nigeria	Turkey
Cameroon	Ireland	Norway	Turkmenistan
Canada	Israel	Oman	Uganda
Cape Verde	Italy	Pakistan	Ukraine
Chile	Ivory Coast	Palestine	United Arab Emirates
China	Jamaica	Panama	United Kingdom
Colombia	Japan	Papua New Guinea	United States
Costa Rica	Jordan	Paraguay	Uruguay
Croatia	Kazakhstan	Peru	Uzbekistan
Cuba	Kenya	Philippines	Venezuela
Cyprus	Korea Rep	Poland	Vietnam
Czech Republic	Kuwait	Portugal	Yemen
DR Congo	Kyrgyzstan	Puerto Rico	Zambia
Denmark	Laos	Qatar	Zimbabwe
Dominican Republic	Latvia	Republic of the Congo	
Ecuador	Lebanon	Romania	
Egypt	Lesotho	Russia	

Table 5: Complete cases and single imputation regression

	complete cases (3SLS)	single Imputation (3SLS)
Aggregate Production		
(Intercept)	16.46	18.08***
	(11.68)	(3.33)
K	0.83***	0.60***
	(0.30)	(0.08)
L	0.06	0.20***
	(0.25)	(0.06)
ICT	2.69*	2.25***
	(1.39)	(0.38)
Demand		
(Intercept)	−4.37***	−5.32***
	(0.85)	(0.24)
GDPC	0.14***	0.02
	(0.05)	(0.02)
P	−0.72***	−0.27***
	(0.27)	(0.04)
URBAN	0.00	0.01***
	(0.00)	(0.00)
EDU	−0.03*	0.01***
	(0.02)	(0.00)
R&D	0.18***	0.13***
	(0.07)	(0.02)
Supply		
(Intercept)	21.61***	32.56***
	(2.32)	(0.88)
P	1.08*	−1.01**
	(0.63)	(0.41)
InterPlatform	−8.22***	−15.27***
	(2.10)	(2.16)
Infrastructure Production		
(Intercept)	0.13	0.26***
	(0.14)	(0.07)
ICTI	−0.00	−0.01***
	(0.01)	(0.00)
Adj. R^2		
Aggregate Production	0.82	0.79
Demand	−0.16	0.41
Supply	−0.26	−1.61
Infrastructure Production	−0.02	−0.01
Num. obs.	167	1085

$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$

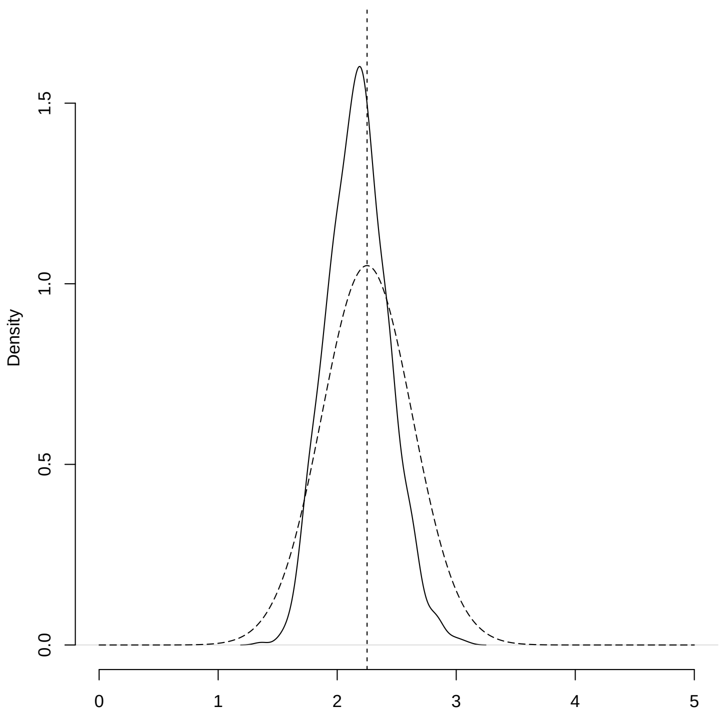
K, L, ICT, GDPC, P, ICTI are log transformed

B. Simulation

The stability of the estimation results is assessed by simulating the imputation process and the subsequent estimation for 1000 times.

- Taking an imputed dataset as given and estimating coefficients which are considered to be the "real" coefficients, a new set of dependent variables are generated. Random errors are drawn from a normal distribution (with the standard deviation being estimated from the original residuals) and added to the newly generated variables.
- In a loop a number of holes, equal the missing share in the original dataset, is added to the dataset and the imputation algorithm is run to impute five datasets. The estimation is run for each of the datasets and the coefficients are combined using Rubin's rules.
- The distribution of the coefficients over several simulations can be analyzed. As an example the coefficient for ICT is shown in Figure 3.

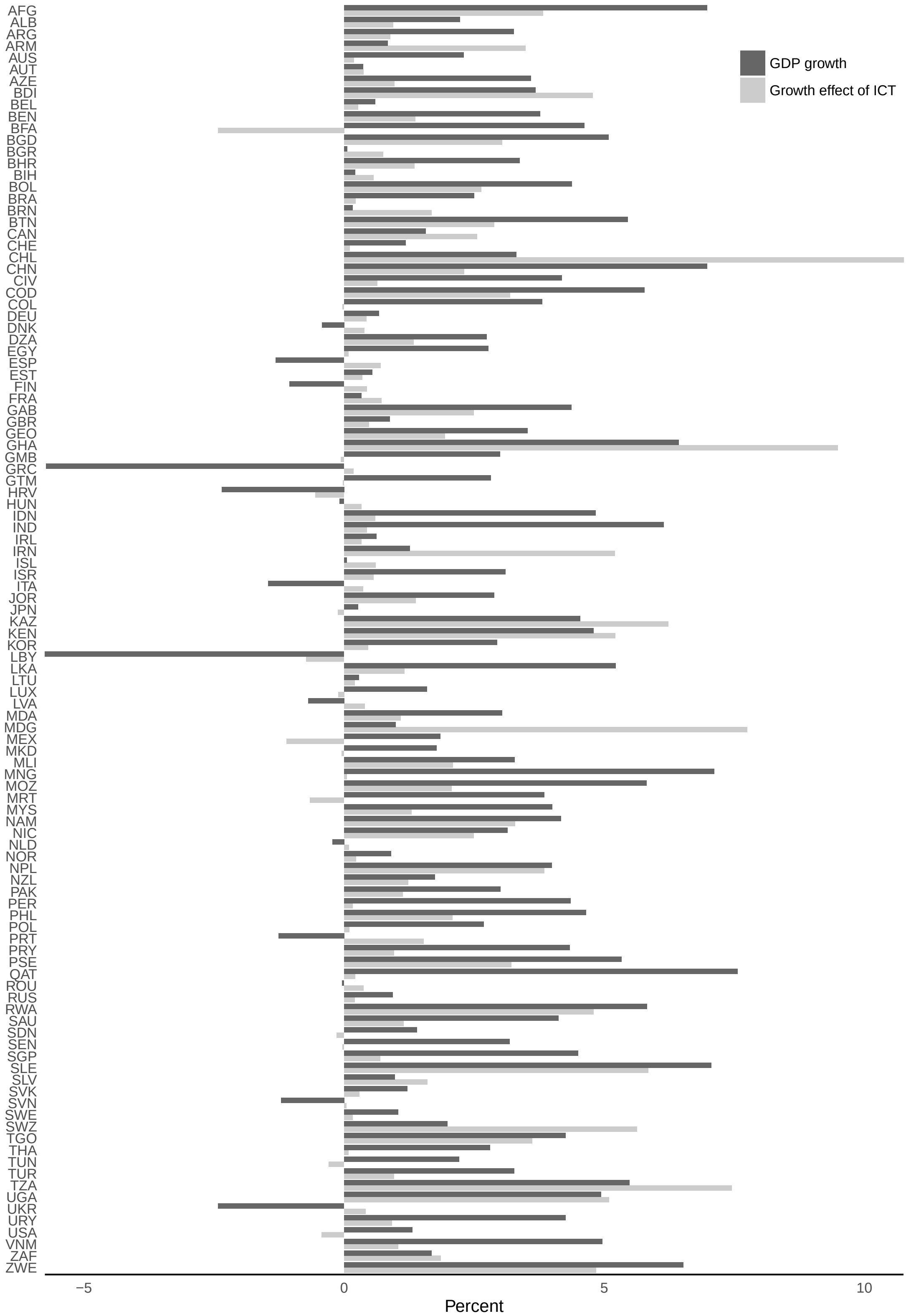
Figure 3: Simulated coefficient (solid) and "real" coefficient (dashed)



Note: Variance for the "real" coefficient is obtained from original standard errors

C. Growth effects

Figure 4: ICT growth effects



Note: Bars are truncated at -5% and +10%