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A literature review on the impact of ICT on economic growth

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Abstract

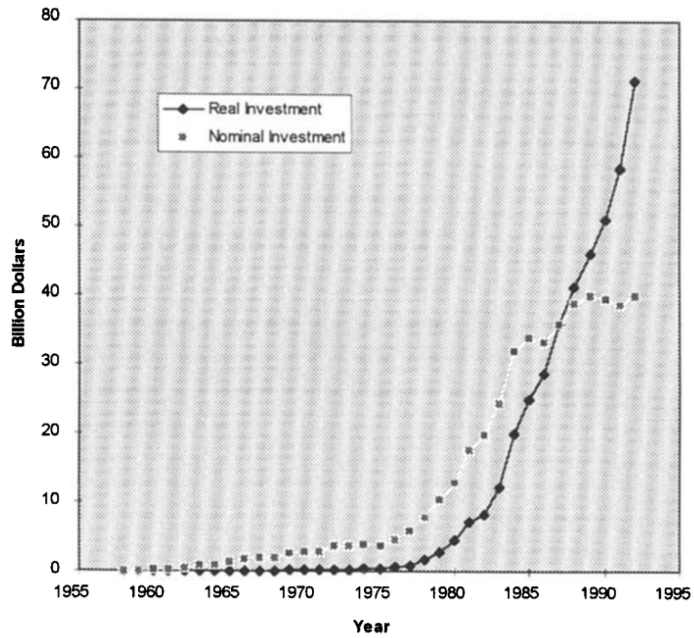
This research tries to conduct a review of the literature on the topic of ICT impact on economic growth. First we try to define what ICT is and discuss the poor empirical results of the 90s. Then, the results of some research are presented. A plethora of econometric techniques has been employed over the years in order to capture the ICT effect and we try to present them as well. Findings from several investigations provide evidence that a positive relationship between ICT and growth exists. Moreover they provide evidence that the US outperforms European countries.

Contexts

1. Introduction

It is true that information and communication technologies (ICT) have conquered the world. Almost every person in the world uses a mobile phone or a computer and has access to the internet. Among other benefits ICT brought the people around the world closer, helped information spread rapidly and made some activities easier. ICT has also entered the industrial sector. Every company and every factory uses information technology capital in order to produce goods and services. From the 80s and 90s companies invested lots of money on ICT as a response to a rapid drop in the price of computers, which led to a higher demand of firms and to a substitution of labor with computers. Jorgenson and Stiroh (1994) claim that in the period 1958-1992 computer prices have decreased by 19% annually, when at the same period investment in computers rose by 44.34%. Barua and Lee (1997) found that this investment in the US reached 1 trillion dollars in the 1980s while the real investment in ICT capital as a share of real fixed business investment increased from 9% to 37% in the period 1974-1994. Also, according to Stiroh (1998) in the US (1958-1992) real computer investment rose from 100 million dollars to 51 billion dollars. Finally Dedrick et al. (2003) claim that the investments in ICT are related to investments in systems such as logistics and of course in employee training on the use of ICT capital while the ICT capital share reached 22% of total capital investment.

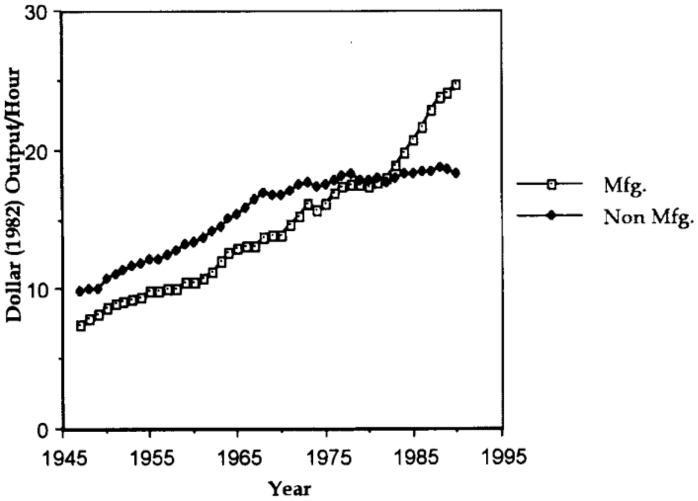
Figure 1. Investment in information technology.



Source: Brynjolfsson and Yang (1996)

Despite that rapid growth in investment, which is also depicted in figure 1 from Brynjolfsson and Yang research (1996), until the mid 90s the empirical research did not provide clear evidence that ICT has a positive effect on productivity. As figure 2 shows, there was a stagnation in growth, especially for the service sector. Moreover, a research by Loveman (1994) shows that the relation between ICT and economic growth is negative. Robert Solow (1987) had understated that problem and he had stated that computers can be found everywhere except in productivity statistics. Roach (1987) called that problem the IT productivity paradox.

Figure 2. Productivity rate in the service and manufacturing sectors.



Source: Brynjolfsson and Yang (1996)

The aim of this research is to make a literature review on the topic of the effect of ICT capital on economic growth. First some definitions on ICT are given and there is a discussion on the ways of measurement of ICT capital. Then a short description of the growth accounting model takes place as it is a pivotal model that is used in literature. After that the econometric models and their empirical results are presented. There is a plethora of methodologies that were used through years in order to capture the effect of ICT on growth so every method is presented separately. Finally, there is a comparison between the results of each research among some other conclusions.

2. Definition and measurement of ICT

Generally, ICT refers to any software, hardware or communication equipment. The "World Bank group defines ICT to consist of hardware, software, networks, and media for collection, storage, processing transmission, and presentation of information in the form of voice, data, text, and images. They range from the telephone, radio and television to the internet" (Pradhan et al. 2019: 1530).

So it is clear that ICT includes a wide range of technologies. However, researches at the first stages of research on ICT impact in the 90s emphasized only on computers as an ICT leading to measurement error. As Brynjolfsson and Yang (1996) note one of the most common definitions of information technology was "the BEA's (U.S. Bureau of Economic Analysis) category "Office, Computing and Accounting Machinery" (OCAM), which consists primarily of computers." (Brynjolfsson and Yang, 1996: 182). The use of this category leaves out of investigation lots of ICT equipment. Moreover, in 90s ICT capital was newly entered into the national accounts and its measurement may not be accurate. In addition Barua and Lee (1997) argues that output measurement for some service sectors is very difficult and as a result the impact of ICT can not be captured. All these facts suggest that there was measurement error in ICT capital and thus, the role of ICT as a driver of economic growth may be underestimated by empirical research.

In the end, it is important to report that even to this day, Official Statistical offices of each country calculates the ICT capital slightly differently. This fact must be taken under consideration when a cross-country analysis is conducted as the data should be modified in order to be comparable.

3. The Growth Accounting Model

The growth accounting model starts with the very familiar Cobb-Douglas production function.

$$Y_{it} = A_{it} f(L_{it}, K_{it}, ICT_{it}) \ (1)$$

$$Y_{it} = A_{it} L_{it}^{\alpha} K_{it}^{\beta} ICT_{it}^{\gamma} \ (2)$$

Where Y is the total output of county i in time t and L is labor. Capital is broken down into two components with K representing non ICT capital and ICT the ICT capital. A is the Solow residual. Constant returns to scale are assumed so $\alpha+\beta+\gamma=1$. After dividing with labor and log linearising (2), (3) is obtained.

$$lny_{it} = \alpha_0 + \alpha_1 lnl_{it} + \beta_1 lnk_{it} + \beta_2 lnict_{it} + \varepsilon_{it} \ (3)$$

Where α_i and β_i are the output elasticities of each input. The error term ε with the constant term α_0 constitute the Total Factor Productivity (TFP) or else multifactorial productivity (MPF) which includes all the parameters that affect labor productivity and are not included in the growth accounting equation.

ICT affects growth in two ways. A direct impact comes through capital deepening which means that the amount of capital per labor increases, while an indirect impact refers to subtle changes in the productivity process due to the use of ICT capital. First, ICT increases TFP which means that total output is increased compared to total inputs due to improvement of technology. Moreover, spillovers or externalities may affect TFP.

This method is very useful as the impact of ICT can be quantified directly and compared to alternative explanations. It also uses aggregate data, which is often the only way to find the sources of productivity. However, despite growth accounting giving effective estimations for the sources of growth it can not give sufficient explanation for the mechanism behind the relation between growth rate and its explanatory variables. Moreover some assumptions of the model such as constant returns to scale and competitive markets impose some restrictions which are embodied on factor shares. In addition, in this framework an increase in capital contributes to growth. However, that is not always the case as some investments are underproductive. Finally, there is a huge variation on the impact of ICT for each sector of the economy. In order to address this heterogeneity some researchers suggest that a disaggregated analysis must be held in order to not underestimate this impact.

Some common assumptions on growth accounting model suppose that there is perfect competition in the markets, there are constant returns to scale, there is complete mobilization of labor and capital which means that wage rates of labor and rental rates of capital are the same. However, sometimes these assumptions may be restrictive and cause problems in research. Thus an alternative method should be employed.

4 The impact of ICT on economic growth

Research in literature gives back lots of interesting findings. Many different econometric methods are used in order to capture the effect of ICT. In this review the results of each method are presented separately and they are compared in the final sector. The main methodologies that will be covered in this part are: the ordinary least squares (OLS) method, the calculation of ICT contribution with by inserting theoretical functions in production function (statistical analysis), the generalized method of moments (GMM), the vector error correction model (VECM), the meta regression analysis (MRA), the partial least squares (PLS) method and the semi parametric analysis. Finally some other methodologies have been grouped as they are presented briefly.

4.1 The OLS method

Barua and Lee (1997) criticize the modelazation of growth accounting. They state that studies did not benefit from profit maximization or cost minimization analysis. In order to improve the analysis they do not use just a nonoptimization model with a Cobb-Douglas production function. They support that optimal choices are very important in economics, so they insert microfoundation and they create an optimization model by using a profit function which must be maximized. In this way they include the prices of inputs and outputs which are pivotal factors of choosing the optimum level of production and must be taken under consideration.

After addressing these methodological problems researchers estimate two models. Data derived for the period 1978-1984 in the US by the Strategic Planning Institute (SPI), Boston. First they estimate with the ordinary least squares (OLS) method a nonoptimization model with the Cobb-Douglas function where ICT capital has a positive and significant effect while other key inputs such as labor and non ICT technologies do not have a significant contribution to the output. To deal with this problem they estimate with the full information maximum likelihood method an optimization model with a translog production function (4) where input variables (i, j) are assumed as endogenous.

$$lny = \alpha_0 + \sum_{i=1}^{k} \alpha_i lnx_i + \alpha_t t + \sum_{i=1}^{k} \beta_{ti} t lnx_i + 1/2\{\sum_{i=1}^{k}\sum_{j=1}^{k} \beta_{tj} lnx_i lnx_j + \beta_{tt} t^2\} + \varepsilon \quad (4)$$

This model gives much better results as all variables have significant contribution to output at 1% level. These results are depicted in the tables 1 and 2. It is clear that when inputs are considered as endogenous the effect of ICT is smaller.

	Table 1. Productivity model estimation with exogenous inputs.		Table 2. Productivity model estimation with endogenous inputs.	
Parameter	Estimate	T -statistics	Estimate	T -statistics
Constant	−1.311	-3.36^{**}	−9.30	-29.99^{***}
Labor	.171	1.96^{*}	.291	22.21^{***}
Structure	.130	2.34^{**}	.086	10.34^{***}
Non-IT	−.064	−.79	.372	11.40^{***}
IT	.683	6.40^{**}	.147	34.01^{***}
Inventory	.072	.32	.101	3.07^{***}
Time trend	.035	1.22	-.028	-1.12

Adjusted R^2 = .927

Source: Barua and Lee (1997)

Nasab and Aghaei (2009) conducted an investigation using fixed and random effects methodology. All data comes from the World Bank tables (2007) but the data on Oil income are obtained from the OPEC Annual Statistical Bulletin (OPEC, 2005). The period of investigation is 1990-2007. The countries of the sample are the 11 members of OPEC. This research is the first to examine the impact of ICT on growth for the countries of OPEC as a whole. The basic equation is:

$$lnGDP_{it} = lnKict_{it} + lnK_{it} + lnHC_{it} + lnRO_{it} + lnFDI_{it} + U_{it} \quad (6)$$

Table 4. Estimation results of the relationship between ICT investment and economic growth

Variable	Fixed-Effects Coefficients	Random- Effects Coefficients
Kict	0.0267*** (3.85)	0.0277*** (3.92)
k	0.0122** (2. 18	0.0312** (2. 22)
HC	0.0121* (1.80)	0.0135* (1.75)
Ro	-0.0138** (-1.89)	-0.0455* (-1.60)
FDI	0.046** (2.0035)	0.0153** (1.98)
Constant	1.23** (2.23)	0.99** (2.027)
R^2	0.62	

Source: Nasab and Aghaei (2009)

Where HC is human capital, FDI is foreign investment as an indicator of technical and technological improvement, and RO represents oil income as a share of GDP.

Employing the fixed and random effects methodology, authors find a significant and positive relation between growth and ICT. The Hausman test favors the fixed effect model against the random effect one where the ICT coefficient is slightly lower as table 4 shows.

4.2 Statistical analysis

Stiroh (1998) attempts to give another solution to the IT productivity paradox. He claims that the contribution of ICT (including only computers) must be examined separately for each sector of the economy. He suggests that even though all sectors substitute expensive labor with cheaper computers this change has a different effect on each sector's output. In other words, a great effect on some sectors is canceled due to a very small effect on others. For this reason after using 35 sectors he estimates the following regression for period 1947- 1991 and for two sub periods (1947-1973, 1973- 1991):

$$\Delta Y_n = \alpha_{K,1,n}\Delta K_{1,n} + \alpha_{K,2,n}\Delta K_{2,n} + \alpha_{L,n}\Delta L_n + \alpha_{M,n}\Delta M_n + v_{T,n} \quad (5)$$

Where Y is output, $K_{1,n}$ stands for non-ICT capital, $K_{2,n}$ represents the ICT capital services, L_n is labor input, M_n is material intermediate inputs, a is the nominal share of each variable in Gross Output and $v_{T,n}$ is the (Multi-Factor Productivity) MFP growth rate, all for sectors n. Constant returns to scale are imposed. Stiroh deploys the dataset of Jorgenson, Gollop and Fraumeni (1987) and he updated the data until 1991. This dataset contains a set of input-output accounts and Gross Output production functions for 35 sectors that make up the private, domestic US economy.

The sector to sector analysis is also justified by Brynjolfsson and Yang (1996) as they claim that even if there is a great rise in ICT investment the economic growth may not increase in the same way because there are many factors that drive it so the contribution of ICT capital is not so big. Furthermore, This rise occurs throughout a vast period of time which means that the relatively smaller change in growth happens quite slowly.

As table 3 notes, most of the computer capital, which was considered as ICT capital, was used in the services sector. However as it is widely stated, this sector had the greatest productivity slowdown than the other sectors. This stagnation was linked to the poor performance of ICT capital in the services sector. However, research shows that ICT capital has a significant effect in the manufacturing sector. For these reasons, aggregation analysis does not give sufficient results for the connection between ICT and growth.

The results show that for the whole period the contribution of ICT is greater than 4,0% in eight sectors. These few sectors used 88% ICT capital services at the period of research. So it is clear that ICT do not have a great impact on many sectors because they do not use much of this input anyway. This fact affects the results for the aggregate economy underestimating the importance of ICT. Another important finding of this paper is that in the second period all sectors (except two) showed an increase in growth contribution of ICT capital. Moreover, these increases combine with substitution between ICT and other inputs as their contribution decreased in the second period.

Table 3. Investment in computers (OCAM) in the US economy (percentage of total in current dollars)

Industry	1979	1989	1992
Agriculture	0.1	0.1	0.1
Mining	2.4	1.1	0.9
Manufacturing	29.4	20.3	20.2
Construction	0.1	0.3	0.2
Nonservice Total	32.0	21.8	21.4
Transportation	1.3	2.0	1.0
Communication	1.5	1.4	1.5
Utilities	1.2	2.8	2.8
Trade	19.9	16.3	20.0
Finance	32.5	38.7	37.8
Other Service	11.6	17.0	13.9
Services Total	68.0	78.2	78.6
Unmeasurable Sectors	67.7	77.6	71.9
Plus consumer and government purchases	67.7	77.6	77.0
Unmeasurable sector output	63	69	70

Unmeasurable sectors: construction, trade, finance and other services; in these sectors outputs are difficult to measure, relative to measurable sectors.

Source: Brynjolfsson and Yang (1996)

Schreyer (2000) conducted research in G7 countries from 1985 to 1996. The author tries to capture the impact of ICT on growth treating this input as a special capital input. This means that not only ICT has a direct effect on growth through capital deepening but also an indirect through positive externalities. This out of income share effect enters the growth accounting equation through the coefficient θ. This research refers to ICT only as hardware.

$$\widehat{Q} = s_L\widehat{L} + s_{KC}(1 + \theta)\,\widehat{K_c} + s_{KN}\widehat{K_N} + \widehat{A} \quad (7)$$

Yet, the author notes that the direct measurement of θ is very difficult. So it must be captured from the MPF which involves all the factors which affect growth and are not included in the growth accounting equation.

$$MPF = s_{KC}(\theta)\,\widehat{K_c} + \widehat{A} \quad (8)$$

There are two main problems with the measurement of ICT. First, there is a huge improvement through time in the quality of ICT equipment leading to a constant reduction of computers' prices. Second, each country follows a different method of measurement of ICT which makes measures incomparable. For this reason the author suggests that a harmonized price index must be employed. This index considers that price changes for capital occur in the same way for all countries. The author highlights that this restriction causes some other issues such as it extinguishes the cross country differences. However, it is the author's opinion that these biases are way smaller than the original bias caused by different ways of measurement.

After dealing with these issues, results show that "in all G7 countries, the share of IT capital goods in total investment expenditure has steadily increased and now accounts for about 10% of total nonresidential gross fixed capital formation or about 20% of total producer durable equipment expenditure"(Schreyer, 2000: 10).

The income share of ICT capital is calculated with the next formula. Where μ_i is the user cost of ICT input and the six non ICT asset types. By this factor ICT enters the growth accounting model.

$$Income\ share\ of\ ICT\ capital = \frac{ICT\ capital\ income}{Total\ capital\ income} = \frac{\mu_{ICT}K_{ICT}}{\sum^{6}\mu_i K_i} \quad (9)$$

The estimated values for each income share of ICT capital is depicted in table 5. First the value of the coefficient rises through the years. The US leads this process as there is an acceleration in the rate of income share of ICT because of high levels of investment in ICT, while most of the European countries are way behind and Canada has a similar rates to the US. Italy and the UK follow the pattern of the US but at a lower rate. The rest of the countries showed a decline in the third period, following the decline of the growth rate. Finally, the calculation of MPF shows it grows at a slow rate which implies that positive spillovers from ICT are not very important. Yet, in the last years of the period an acceleration of the MPF growth rate appears in the US.

Table 5. ICT contribution to output growth Total industries, based on harmonized ICT price index

	Period	Canada	France	W. Germ.	Italy	Japan	UK	US
Growth of output	1980-85	2.8	1.7	1.4	1.4	3.5	2.1	3.4
	1985-90	2.9	3.2	3.6	3.0	4.9	3.9	3.2
	1990-96	1.7	0.9	0.9	1.2	1.8	2.1	3.0
Contribution from ICT (percentage point)	1980-85	0.25	0.17	0.12	0.13	0.11	0.16	0.28
	1985-90	0.31	0.23	0.17	0.18	0.17	0.27	0.34
	1990-96	0.28	0.17	0.19	0.21	0.19	0.29	0.42

Source: Schreyer (2000)

Colecchia and Schreyer research (2002) also employs the growth accounting model. Yet again ICT capital enters in the equation separately as K^C. Estimating the equation by a Tornqvist index number, the contribution of ICT calculated as

$$\sum_{i \in R1} 0.5(v^i_{K,t} + v^i_{K,t-1}) \Delta ln K^i_t \quad (10)$$

$$v^i_{K,t} \equiv u^i_t K^i_t / P_t Q_t \quad (11)$$

Where R1 is a subset of ICT assets, u is the gross rate of return on a new capital asset and K^i is the capital of type i. In order to compare different vintages of ICT capital their price changes must be quality adjusted. So harmonized price indexes are employed. Research is held among nine OECD countries for the period 1980-2000. Data comes from different Official Statistical offices in OECD countries and they must be modified in order to be comparable.

Results in table 6 show that for the period 1980-1995 the contribution of ICT varies among countries from 0.2 to 0.5 percent. However after 1995 this effect rose to 0.3 to 0.9 percent. The country where the ICT contribution is the greatest is the US followed by Australia, Finland, and Canada. Once more the European countries are way back of the US. The fluctuation of the percentage of contribution follows the pattern of Schreyer (2000) estimation. Moreover, the decrease of ICT contribution in the early 90s is followed by a huge rise until the end of the decade. However, unlike Schreyer's research there is a stagnation in the rate of the US and the UK does not catch up the US.

In addition, research provides evidence for the impact of IT and communications equipment and software separately. IT and communications equipment seems to have a stronger effect on growth than software in all cases.

Table 6. Percentage Point Contribution of ICT to Output Growth (Business Sector)

	Australia	Canada	Finland	France	Germany	Italy	Japan	UK	US
1980-85	0.27	0.32	0.18	0.14	0.10	0.13	0.09	0.12	0.44
1985-90	0.51	0.36	0.25	0.21	0.16	0.20	0.18	0.23	0.43
1990-95	0.47	0.28	0.01	0.13	0.22	0.10	0.14	0.15	0.43
1995-99	0.78	0.47	0.20	0.26	0.21	0.16	0.29	0.28	0.86
1995-00	0.79	0.51	-	0.27	0.22			0.27	0.87

Source: Colecchia and Schreyer (2002)

In another research by Oliner and Sichel (2002), the US economy breaks down to five sectors for the period 1974-2001. Four sectors produce final products. Each of the first three produces one of the components of ICT (hardware, software and communication equipment). The fourth produces all non ICT products and services and finally the fifth produces intermediate goods. All these elements can be included in a growth accounting model. Considering capital consists of goods from the first four sectors the mathematical manipulation leads to the next equation:

$$\Delta Y - \Delta H = \sum_{j=1}^{4} \alpha_j^{K}(\Delta K_j - \Delta H) + \alpha^{L}\Delta q + \Delta MPF \quad (12)$$

$$L = qH \quad (12.1)$$

Where K_j stands for the product of each sector (j=1,...,4). Authors estimate labor L as the product of the amount of hours worked H and the labor quality q which the authors allow to change over time. All variables are in logarithms and in growth rates. So in the equation labor productivity and capital per worker are used.

According to BLS income shares are estimated as:

$$\alpha_j = (R + \delta_j - \Pi_j)T_j p_j K_j / pY \quad (13)$$

This equation suggests that income share of each sector is equal to the nominal net rate of return on capital R, which is common for each sector plus the depreciation rate δ and any other changes in price Π, multiplied by a tax rate T and the current-dollar stock of each capital pK as a share of total current-dollar income pY.

$$\Delta MPF = \sum_{i=1}^{4} \mu_i \Delta MPF_i + \mu_s \Delta MPF_s \quad (14)$$

MPF can also be decomposed into two parts. The first is the effect of the four final product producing sectors (i=1,...,4) and the second is the effect that comes from the sector of intermediates. One final equation which is important for the analysis is:

$$\Delta MPF_i = \Delta MPF_0 - \pi_i + \textit{term for the relative growth in sectorial input costs} \quad (15)$$

Where π_i denotes the difference in output price inflation between sector i and the non-ICT sector.

Table 7. Contributions to Growth in Labor Productivity, Using Latest Data

	1974-90	1991-95	1996-2001	Post-1995 change
1. Growth of labor productivity	1.36	1.54	2.43	.89
Contributions from:				
2. Capital deepening	.77	.52	1.19	.67
3. Information technology capital	.41	.46	1.02	.56
4. Computer hardware	.23	.19	.54	.35
5. Software	.09	.21	.35	.14
6. Communication equipment	.09	.05	.13	.08
7. Other capital	.37	.06	.17	.11
8. Labor quality	.22	.45	.25	-.20
9. Multifactor productivity	.37	.58	.99	.41
10. Semiconductors	.08	.13	.42	.29
11. Computer hardware	.11	.13	.19	.06
12. Software	.04	.09	.11	.02
13. Communication equipment	.04	.06	.05	-.01
14. Other sectors	.11	.17	.23	.06
15. Total IT contribution	.68	.87	1.79	.92

Source: Oliner and Sichel (2002)

These four equations are employed in order to decompose the growth of labor productivity in the USA. The data are derived from the Bureau of Economic Analysis (BEA) and the Bureau of Labor Statistics (BLS) for the period 1974-2000. Data for 2001 were constructed by investigators. The sample break into three periods (1974-1990, 1991-1995 and 1996-2001)

Table 7 shows how labor productivity growth is decomposed. Line 15 shows the total contribution of ICT from both of the two channels of capital deepening and MPF. An important raise on the contribution rates of ICT can be noticed. Especially from the second to third period where the raise reaches 106%. Moreover the total contribution of ICT in the third period reaches 74% of the labor productivity. The effect of ICT that comes from capital deepening is always greater than the effect of MPF reaching 66% of total ICT contribution in the last period. Moreover, the direct impact of ICT through the capital deepening channel reaches 42% of total growth in the last period. Finally the component of ICT which has the greatest impact on growth is computer hardware for both channels.

Next the authors try to calculate the steady state value of the dependent variable. Upon manipulation on the growth accounting model they get:

$$\Delta Y - \Delta H = \sum_{j=1}^{4} \alpha_j^K / \alpha^L (\Delta MPF_i + \beta_i^s \Delta MPF_s) + \Delta q + \Delta MPF \quad (16)$$

After setting upper and lower bounds to all variables they get the value of labor productivity as it is shown in table 8. Under both circumstances the labor productivity reaches higher levels of growth than those which were estimated for the period 1974-2001. However the lower bound scenario does not provide a better result than the period 1996-2001 but these forecasts are still very optimistic. Yet again the leading role in total contribution belongs to ICT capital. Once more results are very optimistic with lower bound scenario giving an underperforming value compared to the 1996-2001 period.

Table 8. Steady-State Results

	Using Upper Bound Parameters	Using Lower Bound Parameters
1. Growth of labor productivity	1.98	2.84
Contributions from:		
2. Induced capital deepening	.97	1.47
3. Information technology capital	.88	1.31
4. Other capital	.09	.16
5. Labor quality	.30	.30
6. Multifactor productivity	.72	01.07
7. Total IT contribution	1.50	2.17

Source: Oliner and Sichel (2002)

In order to calculate the impact of ICT investment on economic growth, Jorgenson and Vu (2005) employ the growth rate of IT capital inputs as a share of the value of output.

Data comes from G7 and 103 more economies. First, GDP, which is used as a proxy of capital, is derived by the Penn tables. The U.S. data in Jorgenson (2001) is updated through 2003. Data for Canada has been constructed by Statistics Canada. Data for the economies of the European Union have been developed by van Ark et al. Data for Japan has been assembled by Jorgenson and Motohashi. Finally purchasing power parities of OECD (1999) are employed. Sample breaks into two subperiods 1989-1995 and 1995-2003 as 1995 is considered as a breaking point. There is an acceleration of GDP growth between the two periods from 2.50 to 3.45 globally.

Table 9. Sources of output growth: 1995–2003 vs. 1989–1995

	Period 1989-1995		Period 1989-1995	
Economy	GDP Growth	ICT	GDP Growth	ICT
World (110 economies)	2.50	0.27	3.45	0.53
G7 (7 economies)	2.18	0.38	2.56	0.69
Developing Asia (16)	7.35	0.15	5.62	0.43
Non-G7 (15)	2.03	0.32	3.01	0.49
Latin America (19)	3.06	0.16	2.11	0.39
Eastern Europe (14)	7.05	0.10	2.87	0.23
Sub-Saharan Africa (28)	1.21	0.13	2.88	0.29
N. Africa & M. East (11)	4.36	0.15	4.08	0.40
Seven world major economies (G7)				
Canada	1.39	0.49	2.51	0.65
France	1.30	0.19	1.92	0.36
Germany	2.34	0.26	0.86	0.40
Italy	1.52	0.26	1.48	0.46
Japan	2.56	0.31	1.39	0.56
United Kingdom	1.62	0.27	2.55	0.65
United States	2.43	0.49	3.56	0.88

Source: Jorgenson and Vu (2005)

Table 9 provides evidence that ICT has a positive effect on growth which almost doubled in the second period from 0.27% to 0.53%. Moreover the most benefited countries are those G7. Among the seven countries, the US, Canada and Japan perform better. The effect of ICT in the US is almost twice bigger than in European countries. Even though the UK catches up to the performances of Canada and Japan, it still can not reach the US performance.

Matteucci et al. (2005) conducts another one investigation. Variables come from the dataset of O'Mahony and Van Ark (2003). The analysis took place in 26 industries in the US, Germany, France and the UK. Output is calculated as real gross value added and labor is measured by hours worked. Capital is splitted in six components and three of them refer to ICT. These are computing equipment, software and communications equipment. The investigation is held in two sub periods (1979-1995 and 1995-2000) as 1995 is considered as a breaking point.

Table 10. Growth in labor productivity, and contributions of capital, labor quality and TFP, market economy, average percentage points per annum

	US	UK	France	Germany
(A) 1979–1995				
Labour productivity	1.75	2.93	2.76	2.32
Labour quality	0.27	0.46	0.14	0.24
ICT capital	0.58	0.42	0.21	0.56
Non-ICT capital	0.29	0.95	0.76	0.85
TFP	0.61	1.10	1.65	0.67
(B) 1995–2000				
Labour productivity	3.37	2.86	1.73	2.38
Labour quality	0.16	0.37	0.33	0.06
ICT capital	1.06	0.83	0.34	0.66
Non-ICT capital	0.31	0.19	-0.33	0.57
TFP	1.83	1.47	1.39	1.09

Source: Matteucci et al. (2005)

Considering a Translog production function, growth of output may then be decomposed into its various components in the following way: After dividing with labor, researchers estimate this regression in order to find what drives the growth of labor productivity.

$$ln(\frac{Q^j_t}{Q^j_{t-1}}) = \alpha^j(t, t-1) ln(\frac{L^j_t}{L^j_{t-1}}) + [1 - \alpha^j(t, t-1)] ln(\frac{K^j_t}{K^j_{t-1}}) + ln(\frac{A^j_t}{A^j_{t-1}}) \quad (17)$$

Due to heterogeneity which exists in the adoption of ICT of each sector it is important for a sectoral analysis to be held. For this reason industries are separated into market services and manufacturing. Once more the acceleration of labor productivity growth in the USA is observable. The share of ICT for manufacturing shows a raise for all four countries. This raise is driven by the high rates of the ICT producers sector. Labor productivity in the UK is reduced due to lower TFP rates. In the market services there are two trends. First, the USA and the UK show a significant rise to both labor productivity growth and ICT rate. Second, Germany and France show stagnation despite the small increase of ICT rates. Results are confirmed by table 11. The TFP effect also rises in most cases. This fact implies that due to the use of ICT there are positive externalities. This relation between ICT and TFP can not be

Table 11. Growth in all variables, average percentage points per annum

	US	UK	France	Germany
Manufacturing				
(A) 1979–1995				
Labour productivity	3.43	4.87	2.94	2.81
Labour quality	0.38	0.36	0.28	0.33
ICT capital	0.46	0.29	0.14	0.34
Non-ICT capital	0.48	0.91	1.63	0.58
TFP	2.11	3.31	0.89	1.56
Labor productivity (ICT producers)	12.54	12.56	7.43	4.99
(B) 1995–2000				
Labour productivity	4.69	2.93	3.57	2.26
Labour quality	0.21	0.35	0.23	0.11
ICT capital	0.73	0.57	0.24	0.29
Non-ICT capital	0.73	0.43	0.38	0.22
TFP	03.02	1.58	2.72	1.64
Labor productivity (ICT producers)	21.73	15.68	9.95	8.94
Market services				
(A) 1979–1995				
Labour productivity	1.18	02.01	1.97	2.19
Labour quality	0.27	0.60	0.13	0.21
ICT capital	0.73	0.59	0.25	0.81
Non-ICT capital	0.29	0.86	— 0.08	01.09
TFP	— 0.11	— 0.04	1.67	0.08
(B) 1990–2000				
Labour productivity	3.55	3.40	0.84	2.19
Labour quality	0.15	0.41	0.42	0.05
ICT capital	1.36	1.10	0.39	0.87
Non-ICT capital	0.32	0.19	— 0.77	0.56
TFP	1.72	1.70	0.80	0.71

Source: Matteucci et al. (2005)

captured by the growth accounting model. Table 12 shows the correlation between the two variables. It is clear that ICT has a positive impact on TFP after 1995 in the USA and the UK.

Table 12. Correlation between TFP growth and ICT capital contribution

	1979–1995	1995–2000
US	— 0.14	0.25
UK	— 0.10	0.51
France	0.08	— 0.09
Germany	— 0.45	— 0.05

Source: Matteucci et al. (2005)

4.3 The GMM model

Instead of utilizing the OLS and fixed effect approach, Stiroh (2002) employs the GMM model. This method takes simultaneity and omitted variable concerns under consideration. The equation (18) can be estimated with the OLS method however, when exogenous (unrelated with the inputs) industry specific effects exist then the fixed effects or first difference should be used in order to deal with the problem. The estimation takes place for 49 industries in the US from 1977 to 1996.

$$lnY_{it} = \beta_m lnM_{it} + \beta_L lnL_{it} + \beta_{IT} lnK^{IT}_{it} + \beta_{EQ} lnK^{EQ}_{it} + \beta_{ST} lnK^{ST}_{it} + \gamma_t + \eta_i + v_{it} \quad (18)$$

where Y is output, K^{IT} is ICT capital input, K^{EQ} is other equipment inputs, K^{ST} is structures, M represents the intermediate inputs and L stands for labor,. γ_t are year-specific intercepts. The error term consists of an industry-specific effect η which is unobservable, and a disturbance term $v_{i,t}$.

Another useful tool that can be used for more efficient results is the stacked system of levels and first differences (Static GMM-SYS). This model uses lags of the variables and it is useful when the industry specific effects are endogenous. If there is autocorrelation in error term then the Dynamic SYS-GMM must be employed. In general, the SYS-GMM models consider all independent variables as endogenous. Lags are used as instruments. In the first difference equation lagged levels dated t-2 and in the levels equation dated t-1

The estimations for the three models are in table 13. There is a clear and strong relation between ICT and output growth. However due to the existence of the problems mentioned above the most suitable model is the dynamic GMM-SYS. This model gives the lowest estimation of the share of ICT as it is 0.045%.

Table 13. Production Function Estimates, 1977-96

	OLS		Static GMM-SYS		Dynamic GMM-SYS	
M_t	0.643***	0.713***	0.445***	0.611***	0.163***	0.202***
	(0.051)	(0.048)	(0.150)	(0.076)	(0.031)	(0.031)
L_t	0.250***	0.208***	0.395***	0.225***	0.417***	0.408***
	(0.049)	(0.045)	(0.101)	(0.048)	(0.044)	(0.027)
K_t	0.052		0.062		0.131*	
	(0.042)		(0.074)		(0.073)	
$K_{IT,t}$		0.051***		0.086***		0.045**
		(0.016)		(0.025)		(0.015)
$K_{EQ,t}$		-0.086**		-0.059		-0.019
		(0.033)		(0.045)		(0.060)
$K_{ST,t}$		0.074**		0.083*		0.137***
		(0.035)		(0.044)		(0.035)
Y_{t-1}					0.973***	0.975***
					(0.011)	(0.014)

Source: Stiroh (2002)

In order to address the problem of endogeneity, to find hidden country specific effects and also lagged dependent variables effects Nasab and Aghaei (2009) extend their research and estimate a dynamic panel model using the GMM model.

$$\Delta Y_{it} = \alpha \Delta Y_{it-1} + \beta \Delta X_{it-1} + \gamma \Delta Z_{it} + v_i + \varepsilon_{it} \quad (19)$$

Where ΔY is first differences of real GDP, ΔX_{it-1} is a vector including endogenous variables, ΔZ_{it} is a vector of exogenous variables, v_i captures the country specific effects and ε_{it} is the error term. All variables are in logarithms. Wald Test Statistic rejects the null hypothesis of zero for all coefficients at 1% confidential level. Results are similar to the results of fixed effect panel estimation, however the ICT contribution is rapidly increased.

Strauss and Samkharadze (2011) took data from EUKLEMS, for 13 countries and 22 sectors from 1995 to 2007, authors estimate a Cobb-Douglas production function and they separate capital to ICT (K^I) and non-ICT (K^N). Finally they split labor to high (L^H) and low skilled (L^L). The model is estimated with the Sys-GMM model. So the equation is:

$$lnY_{ijt} = \beta_1 lnK^I_{ijt} + \beta_2 lnK^N_{ijt} + \beta_3 lnL^H_{ijt} + \beta_4 lnL^L_{ijt} + \alpha_{1i} time^C_{it} + \alpha_{2j} time^I_{jt} + \varepsilon_{ijt} \quad (20)$$

Table 14. Estimation results of the relationship between ICT investment and economic growth using the Dynamic Panel Method and GMM estimator.

Explanatory variables	Coefficients	Statistic t
constant	0.99	1.65
GDP(-1)	0.51	2.55
Kict	0.41	5.91
HC	0.055	1.33
RO	-0.009	-2.11
FDI	0.091	1.75
Wald Test Statistic	125.56	
Sargan Test	97.89	
Number of Countries	7	
Number of Observations	126	

Source: Nasab and Aghaei (2009)

Where $time^C$ it denotes the country-specific time trend and $time^I$ it the sector-specific time trend for sector j, in country i, at time t. Both variables try to capture the TFP effect. Results in table 15 show that ICT has an impact on output explaining 0.06% of variance. However this result is possibly insignificant as the variable is statistically significant only on 10% level.

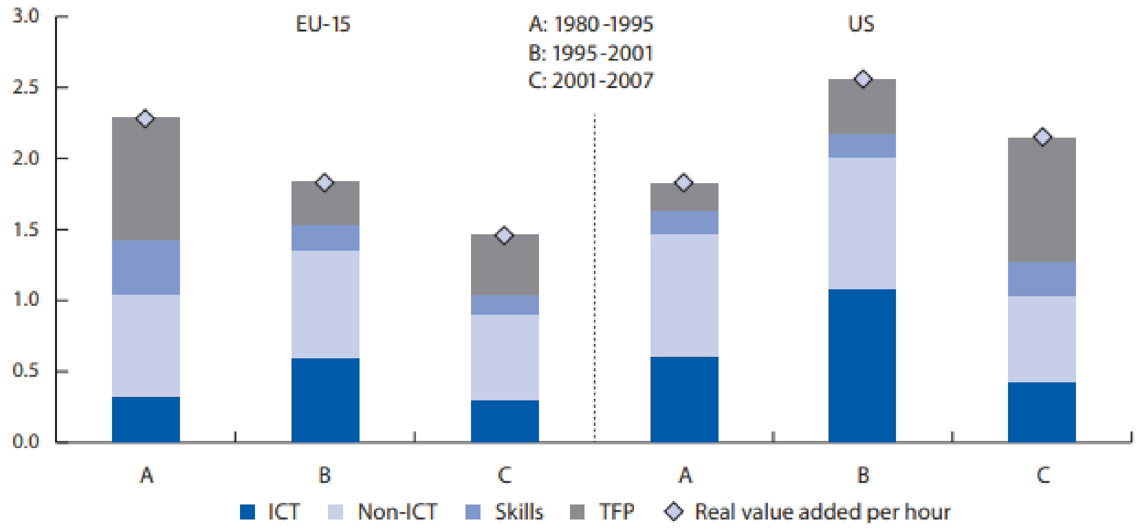
Figure 3 shows the contribution of each input to labor productivity in EU-15 and US for periods 1980-1995, 1995-2001 and 2001-2007. It is clear that at the same periods, ICT has a greater contribution to the US economy than to the EU. Moreover there is an acceleration in labor productivity growth in the US thanks to ICT contribution. ICT capital contribution follows the same pattern in both areas with a raise in the second period (which is sharper in the US) and then a decline in the third period (which is lower in the EU).

Table 15. Estimated output elasticities versus average factor-income shares

High-skilled labour	0.135***
Low-skilled labour	0.473***
ICT capital	0.060 *
Non-ICT capital	0.330***
Total	998

Source: Strauss and Samkharadze (2011)

Figure 3. Contributions to labor productivity growth in the EU-15 and the US
Total economy, average annual contribution (pp.), 1980-2007



Source: Strauss and Samkharadze (2011)

Appiah-Otoo and Song (2021) try to estimate the impact of ICT on growth for 123 countries. In order to achieve that, they allocate these countries into three income groups (low, medium and high income) and they test whether ICT affects growth for each group. Then, they estimate whether the gains of ICT are different for each group. The period of examination is 2002-2017. They employ the growth accounting method starting with a Cobb-Douglas function. An important difference from other investigations is the fact that they insert ICT in the function as a substitution of TFP and not as a part of capital.

ICT infrastructure has been decomposed in three components: mobile $\ln mob_{it}$, internet $\ln int_{it}$, and fixed broadband $\ln fbb_{it}$. The authors try to capture the effect of each component separately.

In order to address heterogeneity they use the IV-GMM method. This method is useful only when the null hypothesis of overidentification should not be rejected. The Hansen test provides evidence that this hypothesis can not be rejected so the estimator is effective.

Table 16 reports that for each income group the three components of ICT have a positive effect on ICT which is statistically significant at 1% level. The same case is confirmed when aggregate ICT capital is used. However, the leading impact for low and high income countries is that of the internet, while for middle income mobile has the leading role. Furthermore ICT capital has much less impact on growth for high income countries than each of its components. The countries of middle income are benefited the most by aggregate ICT capital while those of high income the least. This result suggests that there is a non linear relation between ICT and economic growth.

Table 16. ICT and economic growth.

	1	2	3	4	5	6	7	8	9	10	11	12
		HIC				MIC				LIC		
lnmob	0.262				0.440				0.091			
lnint		0.751				0.353				0.149		
lnfbb			0.319				0.192				0.091	
lnict				0.094				0.422				0.158
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	8.455	7.062	9.332	9.666	6.419	7.715	9.240	8.547	5.404	5.569	5.586	5.195
Observations	630	630	628	628	812	812	753	753	280	275	228	224
R-squared	33	257	232	35	192	284	305	282	174	323	220	197
RMSE	584	512	521	584	672	633	628	638	370	329	355	356
F-statistics	49.21	109.1	88.98	49.59	67.132	128.04	84.82	114.474	24.285	41.870	29.11	20.97
Hansen test	130	2546	3118	148	24	600	799	470	3489	1621	396	37
Hansen test P-value	719	111	77	700	877	439	371	493	62	203	529	847

Source: Appiah-Otoo and Song (2021)

4.4 The VECM method

The aim of the research of Pradhan et al. (2017) is to test whether the Granger causality between innovation and per capita growth (PEG) exists. However, researchers include in the model ICT infrastructure and some more macroeconomic variables (government consumption expenditure, gross capital formation, foreign direct investment, trade openness) because they have an impact on the main relation. There are five different ways to measure innovation the number of patents -residents (PAR), the number of patents - non-residents (PAN), the total number of patents - both residents and non-residents (PAT), the research and development expenditure (RDE) and researchers in research and development activities (RRD). For these reasons five cases are developed, one for each variable. Data provided from World Development Indicators of the World Bank for 32 OECD countries for the period 1970-2016.

First some unit root tests are taking place. In this research four panel unit root tests are employed. All tests indicate that the alternative hypothesis of non-stationary can not be rejected. Stationary obtained after taking first differences. Then, authors search for long run relationships using the cointegration test of Pedroni. Results indicate that innovation has long run relationships with PEG, government consumption expenditure (GCE), gross capital formation (GCF), foreign direct investment (FDI), trade openness (OPE), and ICT infrastructure. VECM is very helpful in order to estimate both long-run equilibrium relationships and short-run fluctuations. The equation for PEG is[1]:

[1] In order to focus on the main topic of this review only the equations and results related to the growth and ICT relationship are presented.

$$\Delta PEG_{it} = \eta_{2INN_j} + \sum_{k=1}^{p_1} \beta_{21INN_{ik}} \Delta PEG_{it-k} + \sum_{k=1}^{p_2} \beta_{22INN_{ik}} \Delta INN_{it-k} + \sum_{k=1}^{p_3} \beta_{23INN_{ik}} \Delta GCE_{it-k} + \sum_{k=1}^{p_4} \beta_{24INN_{ik}} \Delta GCF_{it-k} + \sum_{k=1}^{p_5} \beta_{25INN_{ik}} \Delta FDI_{it-k} + \sum_{k=1}^{p_6} \beta_{26INN_{ik}} \Delta OPE_{it-k} + \sum_{k=1}^{p_7} \beta_{27INN_{ik}} \Delta ICT_{it-k} + \kappa_{2INN} ECT_{it-1} + \varepsilon_{2INN_{it}} \quad (21)$$

Where INN represents each of the five measures of innovation which are used in the five cases. ECT is an error correction term and captures the long-run effect. Results show that for the PEG equation the ECT is statistically significant. This means that if a shock occurs in ICT, for example, economic growth has a tendency to return to the long-run equilibrium. Thus, ICT infrastructure is influential for economic growth in the long run. Moreover Granger causality tests provide evidence that Granger causality between per capita growth and ICT in all five cases is unidirectional.

Pradhan et al. (2019) made another research employing VECM which was held for 50 European countries for a long period of time from 1961 to 2016. This time authors do not use macroeconomic variables so they try to capture the effects between Innovation Diffusion, Per Capita Economic Growth and ICT penetration. ICT penetration is an index that measures the accessibility to ICT services in an economy. Like previous research, innovation is measured with nine proxies. Moreover, this time ICT is decomposed into six components which are mobile phones (MOB), telephone landlines (TEL), fixed broadband, (FIB) internet servers (INS), and internet users (INU). The impact of the five components on growth is examined separately because of the high correlation between them which may cause the error of multicollinearity. In addition authors construct an intex for ICT penetration (CIC) with principal component analysis. Where Innovation diffusion and ICT penetration represent all the proxies which are employed. The Akaike Information Criterion (AIC) is employed in order to estimate the number of lags. The growth equation of the VECM is

$$\Delta Per\ Capita\ Economic\ Growth_{it} = \kappa_{3j} + \lambda_{3i} ECT_{it-1} + \sum_{k=1}^{p_1} \mu_{31_{ik}} \Delta Per\ Capita\ Economic\ Growth_{it-k} + \sum_{k=1}^{p_2} \mu_{32_{ik}} \Delta ICT\ Penetration_{it-k} + \sum_{k=1}^{p_3} \mu_{33_{ik}} \Delta Innovation\ Diffusion_{it-k} + \varepsilon_{3it} \quad (22)$$

The Breitung unit root test suggests that all the variables are integrated of order one and there is possibility for cointegration between variables. Then, the Johansen panel cointegration test verifies that there are long run relationships between all the variables and their proxies. Once more ECT is statistically significant when growth is the dependent variable. The conduction of the Granger causality tests verify that out of 54 cases ICT components affect growth in 50. Moreover most of them show a bidirectional relation and finally only four cases show unidirectional relation of growth on ICT. In order to check for robustness, authors use Mixed effects generalized linear model (GLM) estimation. The results verify the findings of the main analysis. In conclusion, research implies that ICT affects economic growth.

The results of this research are verified by another more recent work for the period 1961-2018. The research was conducted among 36 OECD countries where R&D takes the position of innovation. Once more different proxies are used and among them the six proxies of ICT. Results prove the bidirectional relationship of ICT components and growth in the short run. However the effect of telephone landlines seems to be insignificant. Moreover ECT is statistically significant which proves the influence of ICT on growth once more.

4.5 Meta regression analysis

Stanley et al. (2018) employ a meta regression analysis. This method "is an effective means of synthesizing the results from diverse studies, detecting and correcting biases that arise from the research process (e.g. publication selection bias and econometric model misspecification) and statistically testing hypotheses about the underlying effects." (Stanley et al, 2018: 706) Authors studied more than 1200 studies and they finally made a dataset consisting of 415 estimates for ICT and growth from 58 studies.

First MRA model tries to deal with publication error which refers to the tendency of editors and researchers to use methods and data which are consistent with the conventional theory. Publication bias suggests a positive relationship between standard error (SE) and studies' reported effects (r_i). This relation is depicted in the equation. For better estimation on the size of the effect it is suggested that the SE_i must be used.

$$r_i = \alpha_0 + a_1 SE_i + \varepsilon_i \quad (23)$$

$$r_i = \gamma_0 + \gamma_1 SE_i^2 + v_i \quad (24)$$

If publication bias does not exist then H_0: α_1, $\gamma_1 = 0$ (The FAT hypothesis). α_0 and γ_0 is the empirical effect remaining after potential publication. If there is not an effect then H_0: α_0, $\gamma_0 = 0$ (PET hypothesis). A method of estimating an MRA with partial correlations. Due to possible asymmetry problems Fisher's z-transform must be employed in order to increase the robustness. It is important to note that partial correlation is a statistical and not an economic measure. Because the two models have heteroskedasticity problems, the WLS method must be employed. This estimate weights each ICT–growth estimate by the inverse of its squared standard error. This method provides more accurate results from others, especially when the problems of publishing bias and heterogeneity appear.

Results are shown in tables 17 and 18. It is obvious that even when publication bias is taken under consideration, ICT effect is still significant and positive. However, its value is small around 0.2 which means that it explains only 4% of the variance of economic growth.

Table 17. FAT-PET Meta-Regression Model of Publication Selection – MRA Equation (23).

	Partial correlations			Fisher's z-transformed		
	(1)	(2)	(3)	(4)	(5)	(6)
Variables	WLS	Cluster-robust	Panel	WLS	Cluster-robust	Panel
SE_i: α_1	1.92***	1.92**	0.21	2.46***	2.46***	1.07*
{FAT}	(5.97)	(2.89)	(0.45)	(7.60)	(3.84)	(2.20)
Intercept: α_0	0.109***	0.109*	0.195***	0.080***	0.080	0.148***
{PET}	(6.54)	(2.04)	(9.47)	(4.66)	(1.65)	(6.76)
Number of estimates	415	415	415	415	415	415
Number of studies	58	58	58	58	58	58

Source: Stanley et al. (2018)

Table 19 shows the effect of the components of ICT. In this research ICT consists of four components. These are Landline, Cell, IT and internet. Moreover, in the equation a dummy for developing countries has been included. In this way differences between the effect of ICT on developing and developed countries can be captured. Results show that landline and cell

Table 18. PEESE Corrections for Publication Selection – MRA Equation (24).

	Partial correlations			Fisher's z-transformed		
	(1)	(2)	(3)	(4)	(5)	(6)
Variable	WLS	Cluster-robust	Panel	WLS	Cluster-robust	Panel
γ_0	0.175	0.175	0.206	0.163	0.163	0.182
95% CI	0.155 to 0.195	0.098 to 0.251	0.175 to 0.236	0.142 to 0.184	0.089 to 0.238	0.151 to 0.214
Number of estimates	415	415	415	415	415	415
Number of studies	58	58	58	58	58	58

Source: Stanley et al. (2018)

have the same significant and positive effect for both groups of countries. However, IT is significant and positive for developed countries and almost equal to zero for developing countries. Finally, the internet seems to be insignificant for developed countries but significant and positive for developing countries.

Table 19. WLS-MRA of Partial Correlations by Technology and Level of Development.

	(1)	(2)	(3)	(4)
Variables	Landline	Cell	IT	Internet
SE_i: α_1	0.851	1.320	−0.287	3.185***
{FAT}	(1.76)	(1.27)	(−0.37)	(10.17)
Intercept: α_0	0.117***	0.266***	0.562***	−0.010
{PET}	(4.80)	(4.15)	(8.85)	(−0.73)
Developing	0.005	0.075	−0.477***	0.274***
	(0.15)	(1.02)	(−3.88)	(3.16)
Number of estimates	120	55	48	112
Number of studies	33	14	6	15

Source: Stanley et al. (2018)

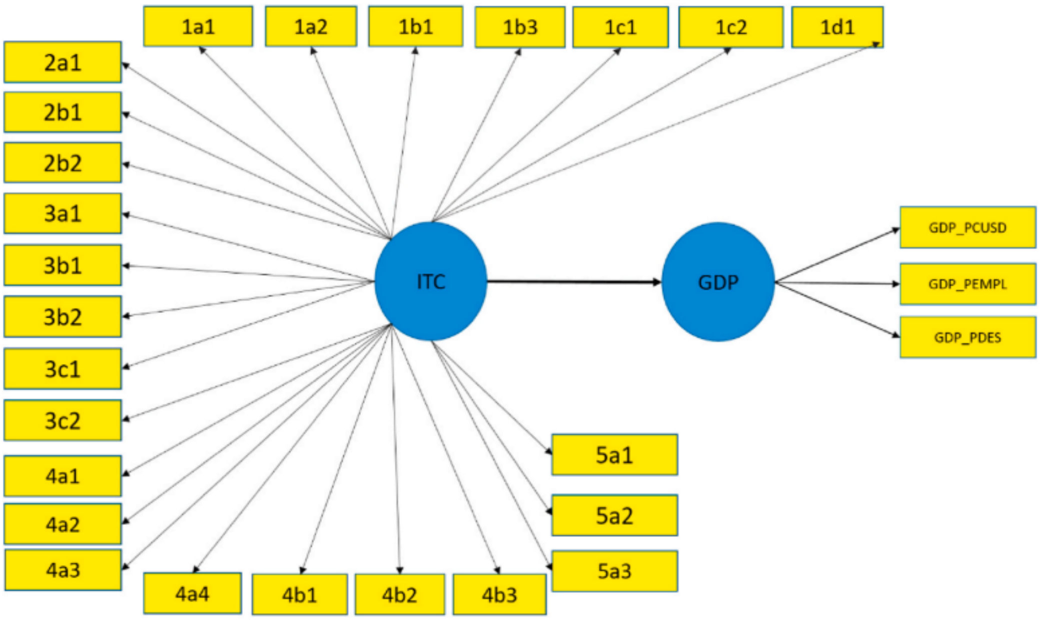
4.6 PLS method

Fernandez-Portillo et al. (2020) study 23 EU countries that are also members of the OECD during the period 2014-2017. The Digital Economy and Society Index (DESI) measures ICT. This is a digital performance and competitiveness index that includes data from EU countries and uses a large amount of data to measure ICT capital, which consists of five components (connectivity, human capital, Internet use, technology integration and public services). Each category contains a subcategory, and each subgroup is divided into indicators. In addition, this study uses three measures of GDP. These are "GDP PC USD constant 2010 PPP", "GDP per employee". Dollar Current Purchasing Power Parity" and "GDP per employee. USD constant 2010 PPP”. The data comes from OECD (2019).

Authors employ the partial least squares (PLS) method. The SmartPLS is designed to predict latent variables based on ordinary least squares estimation and principal component analysis, enabling causal predictive analysis in complex situations. First the construction of a conceptual map that provides all the relations is important. Figure 4 shows all factors affecting ICT. and the relationship between ICT and GDP which construct the global model. This research includes 25 indexes related to ICT connectivity, human digital skills, use of the internet, digitalisation of companies, E-commerce and E-government.

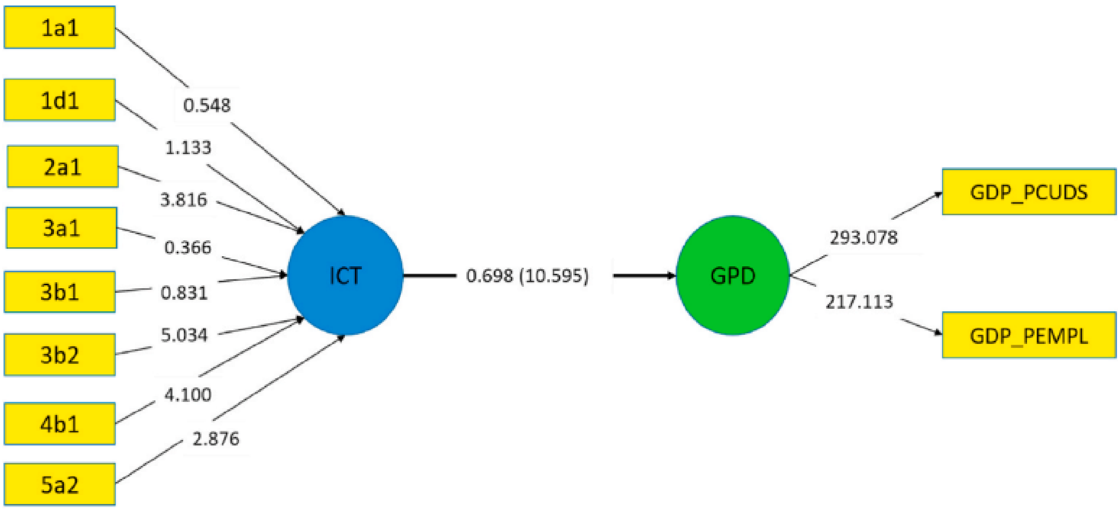
However, in order to demonstrate that the PLS method is suitable for estimating models, some constraints must be met. The SRMR is 0.013, and the NFI is 0.924, meeting the requirements proposed by Hu and Bentler. In addition, the bootstrap-based exact fit test proposed by Henseler, Hubona, and Rai showed more than 95% significance for the SRMR and dG metrics. These results confirm that the PLS approach can provide results for measuring the impact of ICTs on GDP. Some other criteria met are Cronbach alpha value, PLS-SEM, rho_A and Average variance extracted.

Figure 4. Initial Model



Source: Fernandez-Portillo et al. (2020)

Figure 5. Empirically tested model. Stage 2.



Source: Fernandez-Portillo et al. (2020)

Table 20. IPMA analysis result. Performance of indicators on GDP

ICT Indicators		Performance	Performance
Code	Concept	on GDP	on GDP (+1)
2a1	Individuals who use internet regularly	61.427%	59.436%
3a1	Individuals who use the Internet to read online newspapers/magazines	59.368%	57.642%
3b2	Individuals who use Internet to participate in social networks	49.848%	46.635%
5a2	Amount of data that is previously filled in the online Public Services forms	47.724%	48.760%
1a2	Households with fixed broadband access	43.859%	42.289%
4b1	SMEs that sell at least 1% of total sales online	39.840%	38.238%
3b1	Individuals who use the Internet to make video calls	36.032%	34.193%
1d1	Monthly Internet access rate with download speed above 12 and up to 30 Mbps (internet only)	32.794%	32.677%

Source: Fernandez-Portillo et al. (2020)

In the next step the reflective indicators and the formative indicators are estimated with SmartPLS. The indicators that have an IVF value greater than 3.3 or are insignificant are eliminated from the model. The final model is presented in figure 5. This figure shows that ICT has a positive effect on GDP which is statistically significant on a 1% level. Moreover the value of R^2 implies that the model explains 48% of the GDP variance. Finally an Importance Performance Map Analysis (IPMA) is held. This analysis provides evidence on which component of ICT has the greatest influence on GDP. This analysis shows that the most influential component of ICT is the number of internet users and in the second place is the number of individuals who read the news via the internet (table 20). Note that when there is a delay in the indicators the results are improved.

4.7 Semi parametric analysis

Ketteni et al. (2007) suggest that nonlinear relations between ICT and growth may arise due to the fact that countries are at different stages of development and reach steady state with different timing. ICT is more likely to have a higher impact on growth for countries which have high levels of ICT investment than countries which do not invest so much on ICT. These relations prove the existence of heterogeneity. The researchers use the partially additive linear (PLR) model:

$$y_{it} = x_{it}\beta + \theta(z_{1it}, z_{2it}, \ldots, z_{pit}) + \varepsilon_{it} = x_{it}\beta + \sum_{l=1}^{p} \theta(z_{lit}) + \varepsilon_{it} \quad (25)$$

where x_{it} is a q-dimensional variable, b is an aq 1 vector of unknown parameters, zit is a p-dimensional continuous variable, and θ(·) is an unknown function. In this research the nonlinearity of human capital (total mean years education) from Vikram and Dhareshwar (1993), initial income (GDP) from Penn World Tables and ICT from OECD database. The sample includes 15 OECD countries for the period 1980-2004.

After adding marginal integration, which means that the estimator of θ(z) "behaves the same way as if it were a one-dimensional local nonparametric estimator." (Ketteni 2007: 558) the following equation is obtained:

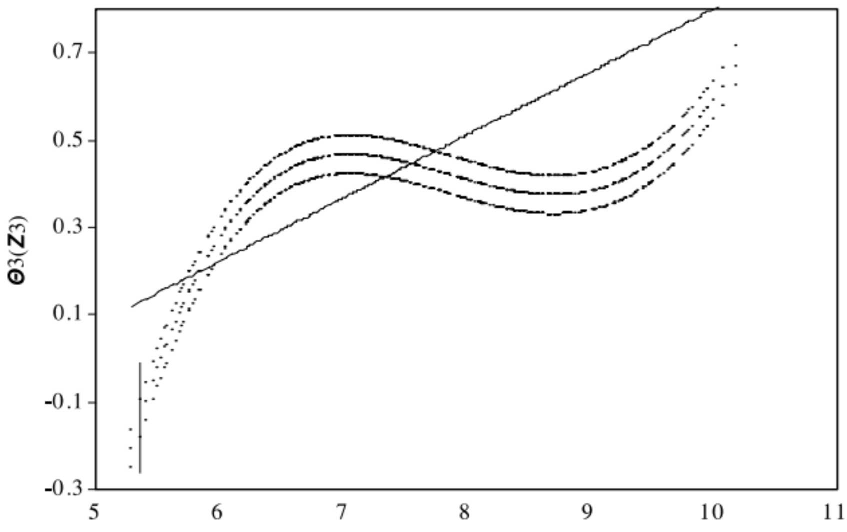
$$y_{it} = \alpha_0 + \sum_{i=1}^{N-1} \alpha_i D_i + \sum_{i=1}^{T-1} \alpha_i D_i + \alpha_3 lns_{it} + \alpha_4 ln(n_{it} + \phi + \delta) + \sum_{l=1}^{p} \theta(z_{lit}) + \varepsilon_{it} \quad (26)$$

where "D_t and D_i are dummy variables for each period and for the countries, respectively, sit is the share of output devoted to non-ICT physical capital accumulation, n_{it} is the growth of population, φ is the rate of exogenous technological change, δ is the depreciation rate for (human, ICT and non-ICT) capital and z1, z2 and z3 are the logarithms of the per capita initial income, human capital per effective worker, and ICT capital growth rate per effective worker, respectively." (Ketteni: 2007: 559)

Figure 6 shows that the effect of ICT for low ICT investment countries increases, then a decrease appears and finally the effect increases again for high levels of ICT. Nonlinearity is also obtained for both initial income and human capital.

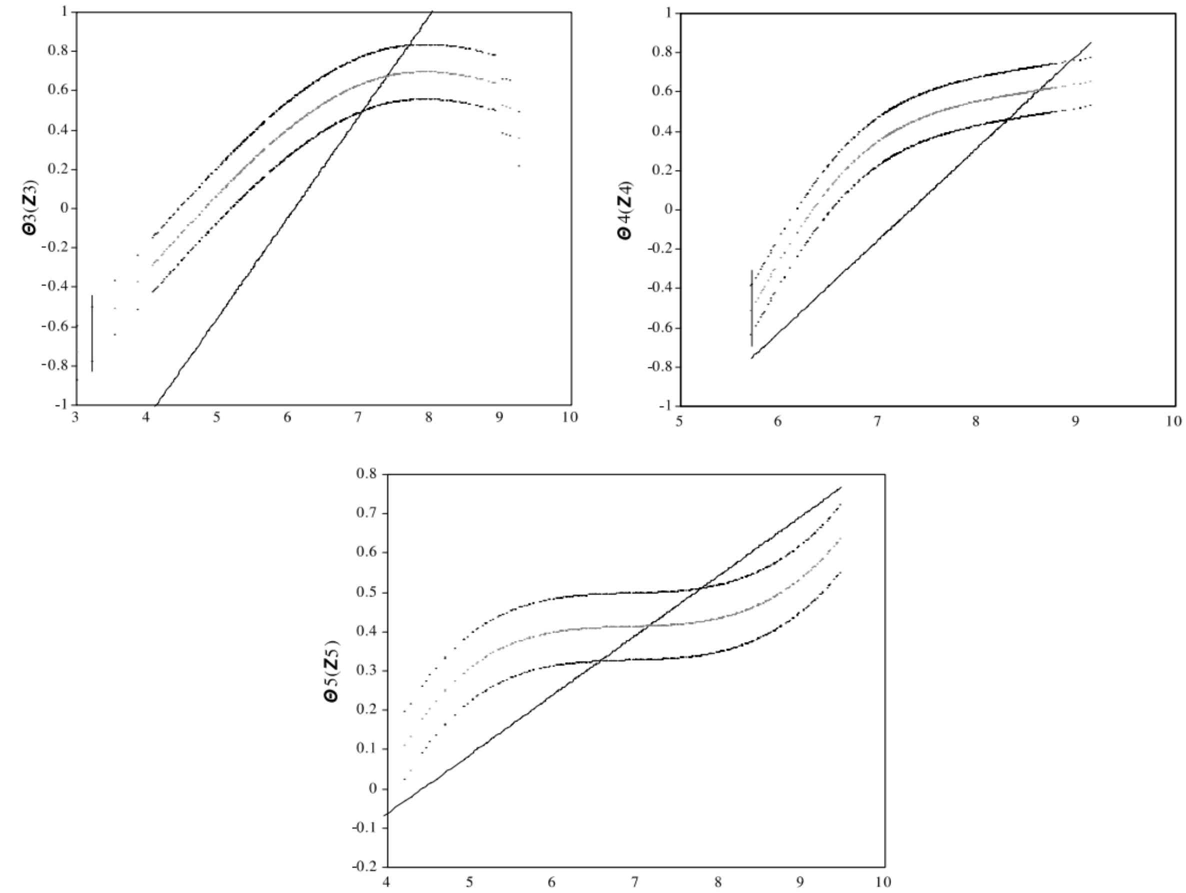
Then they break ICT into three components in order to examine whether each of those components have a nonlinear relation with growth. These measures of ICT are: IT hardware, communication equipment (CE) capital and software (S). In figure 7 it can be observed that all three elements of ICT capital are nonlinearly connected to growth. Specifically, Hardware and CE have almost the same impact on growth. Moreover, the effect of S follows a pattern which is similar to that of aggregate ICT capital.

Figure 6. Semiparametric PLR model conditioned on ICT capital.



Source: Ketteni et al. (2007)

Figure 7. Semiparametric PLR conditioned on IT hardware, CE capital and software.



Source: Ketteni et al. (2007)

Ketteni (2009) employ the sum of a common production function with a function for adjustment cost as her production function. This can be written as:

$$Y = F(X, I, Z, t) \quad (27)$$

Where X is a vector of the inputs which are used. In this model these inputs are non-ICT capital intermediate inputs and labor. I stands for ICT capital and Z is gross investment in ICT. This term captures the potential adjustment costs. Then author employs the Tornqvist index:

$$\widehat{TFP}_{it} = \widehat{Y}_{it} - \sum w_{x_{it}} \widehat{X}_{it} \quad (28)$$

$$w_{x_{it}} = 0.5(s_{x_{it}} + s_{x_{it-1}}) \quad (28.1)$$

Where w_{xit} are weighted averages of the cost shares of physical capital, labor and intermediate inputs. Combining these equations the next equation is obtained:

$$\widehat{TFP} = \alpha_0 + \sum_{i=1}^{N-1} \alpha_i D_i + \sum_{i=1}^{T-1} \alpha_t D_t + \alpha \widehat{M}_{it} + \theta(.)\, \widehat{I}_{it} + \delta \widehat{Z}_{it} \quad (29)$$

$$\widehat{M}_{it} = \sum w_{x_{it}} X_{it} \quad (30)$$

Where D_i is an industry specific dummy capturing the exogenous effect of technological progress and D_t is a time dummy. $\alpha = (\rho-1)$. Where ρ is the elasticity of returns to scale of physical capital, labor, and intermediate inputs. $\theta(.)$ is the smooth coefficient which is a general unknown function which inserts the semiparametric approach in the analysis. Author sets the function to be dependent on all inputs of the model (X_{it}, I_{it}).

The data comes from 42 industries in the US for the period 1984-2001. The main sources of data are Gross Product Originating (GPO) and Fixed Reproducible Tangible Wealth (FRTW) published by the BEA.

Results suggest that α is insignificant, δ is negative and significant and dummies should be included. Different specification tests suggest that non-IT and labor coefficients are insignificant. So analysis is held only with adjustment cost as the linear part of the equation.

Figure 8. IT Output elasticity from the model with linear adjustment costs

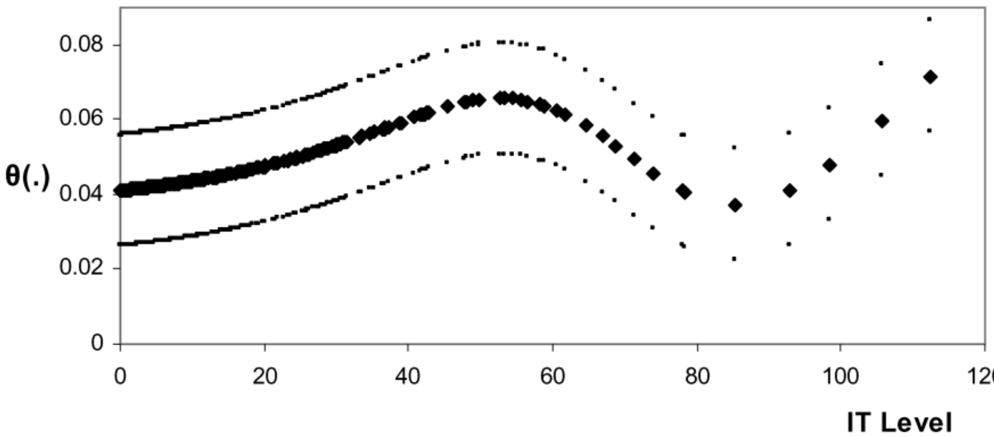


Figure 8 indicates that there is a non linear relationship between ICT and productivity. There is wide variation of output elasticity for different levels of ICT. Yet this effect is positive and appears to be larger for IT-intensive industries.

Ketteni et al. (2010) try to identify the effect of ICT and human capital (mean years of schooling) on economic growth (productivity) with the usage of nonparametric techniques. The results suggest nonlinear relations between ICT and both independent variables. In an attempt to explain if there is a skilled-biased technical change and establish whether the nature of new technologies or their acceleration causes skill-biased technical change, they try to find whether ICT and human capital are complementary. They find that "countries with high levels of ICT capital have high output elasticities of human capital. In addition, countries with high levels of human capital have high output elasticities of ICT, a result suggesting complementarity between the two."(Ketteni et al, 2010: 595) So both ICT and human capital needed in order to succeed growth and the reasons behind skill-biased technical change can not be determined. Their data come from advanced industrialized countries for the period 1980-2004.

Figure 9. Output elasticity of ICT capital, θ_I (I_{it}, H) , holding human capital at the median.

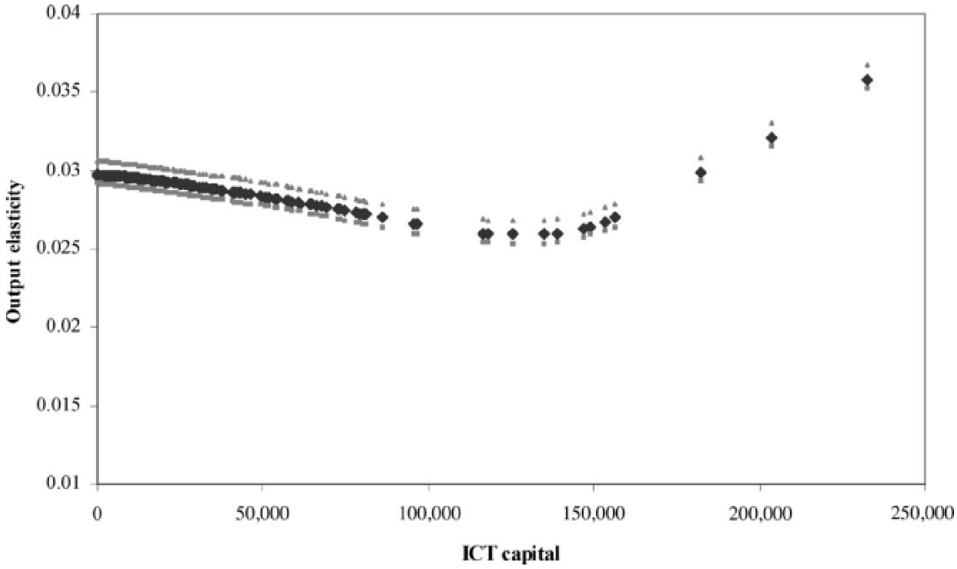


Figure 9 indicates that output elasticity of ICT is higher for higher levels of ICT capital and it is always positive. In other words output increases by a greater growth rate when levels of ICT are high, even if initially there is a decrease.

4.8 Other methods

Among the GMM model, Stiroh (2002) deploys one more econometric method. He tested for structural breaks with Hansen's methodology (1997). He found a break in the year 1995 similar to prior research. So he employed the "Difference-in-Difference" style. This method tries to capture differences in growth rate acceleration between ICT intensive industries and other industries. The equation is:

$$lnA^{Y}_{it} = \alpha + \beta D + \gamma C + \delta CD + \varepsilon_{it} \quad (31)$$

Where A is the productivity acceleration and D, C are dummies. D=1 if year > 1995 and C=1 if industry is ICT intensive. So β shows the difference between the two sub-periods, γ the difference between ICT intensive industries and other industries and δ shows whether this difference is higher in the second period. Data comes from BEA for 57 industries in the US from 1987 to 1999. The analysis of the raw data shows that the output growth rate in the US has been accelerated in the 90s.

How is an industry categorized as ICT intensive? The author suggests that the measure that should be employed is the ICT capital as a share of total capital. However, the author uses some more measures in order to check his findings are robust. These are ICT as a share of output and ICT per full-time equivalent employees (FTE). Moreover he employs the composite index. Finally he makes some estimations for ICT as a share of capital but he drops some outliers that have been identified in raw data. It is important to say that data must undergo adjustment for heteroskedasticity.

Table 23. Dummy Variable Tests of Productivity Acceleration for IT-Intensive Industries

	Alternative Indicators of IT-Intensity						
	IT Share of Capital	IT Share of Output	IT Capital per FTE	Composite	IT Share of Capital		
Constant	1.177*	0.724	0.691*	0.629	1.177*	1.177*	1.177*
	(0.574)	(0.490)	(0.321)	(0.487)	(0.574)	(0.574)	(0.574)
IT-Intensive Dummy	0.434	1.249	2.017**	1.391	-0.024	0.434	-0.030
	(0.847)	(0.780)	(0.770)	(0.774)	(0.648)	(0.853)	(0.649)
Post-95 Dummy	0.120	0.444	0.890	0.290	0.120	0.120	0.120
	(0.665)	(0.521)	(0.580)	(0.436)	(0.666)	(0.666)	(0.666)
Post-95 Dummy*IT-Intensive Dummy	1.371**	1.073	0.532	1.310**	1.282*	1.216*	1,116
	(0.578)	(0.616)	(0.584)	(0.425)	(0.656)	(0.628)	(0.718)
Drop IT-Producing Industries Drop					yes		yes
FIRE Outliers						yes	yes
Number of Obs.	684	684	684	684	660	660	636
Number of Industries	57	57	57	57	55	55	53

Source: Stiroh (2002)

Results in table 23 suggest that δ is statistically significant for the author's preferred index and composite index. Moreover the result is still the same when the subsets are used but only on 10% level. This means that there is evidence for a larger productivity acceleration in the period 1995-1999.

The methodology which has been employed provides some useful information about the contribution of ICT on productivity growth, however, it is a very restrictive model as all information comes from one discrete variable of ICT which does not take under consideration the variation of ICT or a possible link of ICT with other variables. So, author modifies the equation which becomes:

$$lnA^{Y}_{it} = \alpha + \beta D + \eta D \cdot IT_{95} + \varepsilon_{it} \quad (32)$$

where IT_{95} is one of the three IT-intensity variables defined above, normalized by subtracting the mean and dividing by the standard deviation. Results are presented in table 24 and show that there is a strong relationship between the variation of ICT and productivity acceleration with a 0.8 percentage point. This relation implies that industries that used more ICT capital had a higher acceleration.

Table 24. Impact of Continuous Measures of IT-Intensity on Productivity Acceleration

	Alternative Indicators of IT-Intensity					
	IT Share of Capital	IT Share of Output	IT Capital per FTE	IT Share of Capital		
Constant	1.480**	1.480**	1.480**	1.161***	1.479**	1.157***
	(0.481)	(0.481)	(0.481)	(0.303)	(0.485)	(0.305)
Post-1995 Dummy	0.924	1.181**	1.230**	0.828	0.834	0.734
	(0.513)	(0.403)	(0.370)	(0.508)	(0.520)	(0.514)
Post-1995 Dummy * IT-Intensity	0.804***	0.993*	0.792**	0.836***	0.723***	0.753***
	(0.207)	(0.494)	(0.316)	(0.200)	(0.201)	(0.209)
Drop IT-Producing Industries Drop				yes		yes
FIRE Outliers					yes	yes
Number of Obs.	684	684	684	660	660	636
Number of Industries	57	57	57	55	55	53

Source: Stiroh (2002)

The paper of Hanclova et al. (2014) investigates the contribution of ICT investment to economic growth in the EU. The 15 older country members of the EU make up the first group of EU-15 and the newest the second group of EU-12. All data comes from The Conference Board Total Economy Database (The Conference Board 2011). Due to lack of data these groups are reduced to EU-7 and EU-12. Starting from the familiar growth accounting model paper reaches to this equation:

$$gY_{it} = \alpha_0 + \alpha_{it} + \beta_1 gL_{it} + \beta_2 gNICT + \beta_3 gICT + \varepsilon_{it} \quad (33)$$

Where Y is the total output, L is labor quantity in total annual working hours, NICT measures the total investment in non ICT capital and ICT in ICT capital. g means that all variables are in growth rates and α_{it} is the fixed effect term (i for a cross-country analysis and t for period unobservable effect). All variables are in logarithms which means that all variables are in elasticities. Moreover, α_0 is the common constant term. Its existence means that fixed effects should be explained as variations from a general mean. Finally, ε_{it} is the error term. The model is estimated with the panel general least squares method (PEGLS) and with weight correction according to the seemingly unrelated regressions (SUR).

Table 25. Estimation of the model of the production function of the EU-7 countries

Method: Panel EGLS (Cross-section SUR). Sample: 1994–2008 Periods included: 15; Cross-sections included: 7				
Total panel (balanced) observations: 105				
Variable	Coefficient	Std. error	t-Statistic	Prob.
gL	0.093323	0.050478	1.848777	0.0674
gNICT	0.381110	0.057398	6.639780	0
gICT	0.086630	0.017701	4.893968	0
D	2.201090	0.621663	3.540648	0.0006
gNICT_D	–0.266568	0.097051	–2.746679	0.0071
Weighted statistics				
R-squared	0.283481	Mean dependent var		1.622516
Adjusted R-squared	0.254820	S.D. dependent var		1.326838
S.E. of regression	1.004905	Sum squared resid		100.9834
Durbin-Watson stat	1.478989			

Source: Hanclova et al. (2014)

Authors employ some dummy variables in order to catch any differences between the two periods and achieve robust results. These dummies are:

$$gL\_D_{it} = gL_{it}D_{it} \quad (34.1)$$

$$gICT\_D_{it} = gICT_{it}D_{it} \quad (34.2)$$

$$gNICT\_D_{it} = gNICT_{it}D_{it} \quad (34.3)$$

Where $D_{it} = 0$ for the first period of 1994–2000 and $D_{it} = 1$ otherwise. This dummy is multiplied by each interpretive variable. After adding these variables equation becomes:

$$gY_{it} = \alpha_0 + \alpha_{it} + \beta_1 gL_{it} + \beta_2 gNICT + \beta_3 gICT + \alpha_1 D_{it} + \gamma_1 gL\_D_{it} + \gamma_2 gICT\_D_{it} + \gamma_3 gNICT\_D_{it} + \omega_{it} \quad (35)$$

Tables 25 and 26 show that ICT is statistically significant at 1% level of significance and has a positive effect on growth for both EU-7 and EU-14. However, this effect is lower for the whole set of countries. Moreover, the dummy of ICT is also significant so at the EU-14 ICT has a greater effect at the second period.

Table 26. Estimation of the production function model of the EU-14 countries

Method: Panel EGLS (Cross-section SUR). Sample: 1994–2008 Periods included: 15; Cross-sections included: 14

Total panel (balanced) observations: 210

Variable	Coefficient	Std. error	t-Statistic	Prob.
alfa0	1.670655	0.238576	7.002622	0
gL	0.293308	0.006611	44.36825	0
gNICT	0.447321	0.063070	7.092426	0
gICT	0.31398	0.003833	8.191163	0
D	–0.912701	0.227627	–4.009634	0.0001
gL_D	0.245076	0.025920	9.455219	0
gNICT_D	–0.230572	0.075009	–3.073948	0.0024
Weighted statistics				
R-squared	0.909970	Mean dependent var		–0.592897
Adjusted R-squared	0.907309	S.D. dependent var		5.131765
S.E. of regression	1.003599	Sum squared resid		204.4639
F-statistic	341.9666	Durbin-Watson stat		2.003230
Prob (F-statistic)	0			

Source: Hanclova et al. (2014)

For each group of countries the constant returns to scale hypothesis is tested with a Wald test. Null hypothesis for each period is:

H_0: $\beta_1 + \beta_2 + \beta_3 = 0$

$H_0 = \beta_1 + \beta_2 + \beta_3 + \gamma_1 + \gamma_2 + \gamma_3 = 0$

In both cases the null hypothesis is rejected and the verified for literature diminishing returns to scale hypothesis is accepted.

O' Mahony and Vecchi (2005) ran research for 55 industries in the UK and the USA from 1976 to 2000 based on the growth accounting equation. The researchers estimated this equation with standard panel techniques using fixed-effects model with industry-specific dummies. They, also, add time dummies. It is clear that through the years ICT is growing. Time dummies can capture this trend and give a more accurate estimation for the coefficient of ICT capital. Results in table 27 show a negative relation between growth and ICT. Employing a specification with first differences does not change this result.

Table 27. Panel Regressions, Production Function Estimation, 1976–2000

	Fixed-effects estimator Dependent variable: q_{it}		First difference estimator Dependent variable: Dq_{it}	
Variables	(1)	(2)	(3)	(4)
Pooled coefficient				
l_{it}	0.365* (0.021)	-	0.471* (0.065)	-
K_{it}^{N}	0.354* (0.022)	-	0.255* (0.051)	-
K_{it}^{I}	0.074* (0.009)	-	0.039* (0.017)	-
US coefficients				
l_{it}	-	0.380* (0.038)	-	0.648* (0.079)
K_{it}^{N}	-	0.428* (0.039)	-	0.185* (0.086)
K_{it}^{I}	-	-0.079* (0.013)	-	-0.032 (0.022)
UK coefficients				
l_{it}	-	0.339* (0.030)	-	0.266* (0.075)
K_{it}^{N}	-	0.322* (0.027)	-	0.338* (0.062)
K_{it}^{I}	-	-0.068* (0.009)	-	0.042 (0.022)
Adjusted R^2	0.938	0.927	0.295	0.312
CRS	0	0.000 (USA)	0.002	0.150 (USA)
(P values)	-	0.000 (UK)	-	0.001 (UK)

Source: O' Mahony and Vecchi (2005)

In order to deal with this problem, alternative methods are employed. First, they add the growth of non-ICT capital and the ICT capital as independent variables finding a positive relation. Moreover, they hold industry-by-industry research. Findings show that only a few industries have a positive and significant ICT coefficient.[2]

According to the authors, data show heterogeneity as there is variation in investment for each industry which can not be captured just by industry dummies. In addition, variables have a trend which in the case of ICT is very sharp. This problem can be solved with the use of first differences, but, in this case, important information for the industry-specific effects. Finally, the sample has only two countries. All these observations cause problems on the efficiency of the OLS in order to estimate an equation. So they try to find another solution with different econometric methods.

The authors test for stationarity with IPS and Hadri's tests and for cointegration with augmented Dickey Fuller test. Results show that the null hypothesis of no cointegration can

[2] Those results are not included in the paper but the authors provide them on request.

be rejected. This is also the case for stationarity. The long-run relation between variables inserts important information into analysis. For this reason, first differencing is not an effective solution as it drops this information.

The methodology that accounts for heterogeneous dynamic panels is the pooled mean group (PMG) estimator. "The PMG estimator extends the error correction modeling framework to the panel dimension by imposing homogeneity restrictions on the long-run parameters and deriving the error correction coefficient and the other short-run parameters of the model by averaging across groups." (O' Mahony and Vecchi 2005: 623). Another competitive model is the mean group (MG) which "involves simply the estimation of separate equations for each industry and the computation of the mean of the estimates, without imposing any constraint on the parameters." (O' Mahony and Vecchi 2005: 623) Hausman test provides evidence of the homogeneity of the long-run coefficients as it tests whether PMG and MG estimators are not different. Starting with an autoregressive distributed lag (ARDL) (1,1,1,1):

$$q_{it} = \mu_{it} + \delta_{10i} l_{it} + \delta_{11i} l_{it-1} + \delta_{20i} k^{N}_{it} + \delta_{21i} k^{N}_{it-1} + \delta_{30i} k^{I}_{it} + \delta_{31i} k^{I}_{it-1} + \lambda_i q_{it-1} + \varepsilon_{it} \quad (36)$$

An error correction model (ECM) is obtained:

$$\Delta q_{it} = \varphi_i (q_{it-1} - \theta_{0i} - \theta_{1i} - \theta_{1i} l_{it} - \theta_{2i} k^{N}_{it} - \theta_{3i} k^{I}_{it}) - \delta_{11i} l_{it} - \delta_{21i} k^{N}_{it} - \delta_{31i} k^{I}_{it} + \varepsilon_{it} \quad (37)$$

The Schwarz–Bayesian information criterion (SBC) is employed in order to determine the order of lags subjected to a maximum lag of 3. Results in table 28 show that the ICT short run coefficient is statistically significant and positive. Moreover when demeaned data is used (which is equal to adding time dummy variables) the impact of ICT is rising and the speed of adjustment is almost doubled. Moreover the null hypothesis of homogeneity can not be rejected by the Hausman test.

Table 28. Pooled Mean Group Estimates, 1976–2000 (31 US Industries, 24 UK Industries)

Variable	Raw data	Hausman test	Demeaned data	Hausman test
l_{it}	0.675** (0.016)	0.840 (0.360)	0.841** (0.016)	2.480 (0.120)
K_{it}^{N}	0.155** (0.016)	2.250 (0.130)	0.104** (0.017)	2.240 (0.130)
K_{it}^{I}	0.055** (0.002)	3.430 (0.060)	0.066** (0.004)	0.148 (0.220)
Joint Hausman test	4.720 (0.190)		4.470 (0.210)	
ECM	-0.480** (0.061)		-0.825** (0.092)	
CRS (P values)	0		0.637	
Excess returns test	0.005 (0.007)		0.033** (0.009)	

Source: O' Mahony and Vecchi (2005)

To check whether the results are robust, labor quality is used as a control variable. The ICT coefficient is still significant and positive. Finally the authors hold a country by country results with demeaned data. Even though the results in table 29 are consistent with theory for the USA, the UK shows very different results as ICT has a negative effect on ICT. This is plausible because the USA is leading the ICT investment.

Table 29. Individual Country Results, 1976–2000 USA 31 Industries UK 24 Industries

Variable	Demeaned data	Hausman test	Demeaned data	Hausman test
l_{it}	0.563** (0.035)	0.000 (0.950)	0.515** (0.025)	1.910 (0.170)
K_{it}^{N}	0.348** (0.040)	3.040 (0.008)	0.314** (0.014)	0.920 (0.340)
K_{it}^{I}	0.180** (0.014)	0.230 (0.630)	-0.013** (0.005)	0.020 (0.880)
Joint Hausman test	3.340 (0.340)		4.050 (0.260)	
ECM	0.905** (0.081)		0.730** (0.146)	
CRS (P values)	0.132		0.000	
Excess returns test	0.073** (0.021)		-0.120 (0.009)	

Source: O' Mahony and Vecchi (2005)

In the research of Hwan-Joo Seo et al. (2009) countries are categorized into those that lead technological change and into those that lagged behind the technological change. Authors start from the simple Cobb-Douglas equation. After making some assumptions on the calculation of each variable they reach the next system of equations.

$$pro_i = \chi d_0 + \varphi\phi_0 + \chi\theta G_i + \varphi\phi_1 tert_i + \varphi\phi_2 ipr_i + (\alpha - 1)\,\overline{l}_i + \beta nict_i + \gamma ict_i \quad (38.1)$$
$$nict_i = nict_0 + \eta_1 y_i + \eta_2 r_i + \eta_3 gov_i \quad (38.2)$$
$$ict_i = nict_0 + \lambda_1 y_i + \lambda_2 r_i + \lambda_3 gov_i + \lambda_4 tert_i + \lambda_5 open_i + \lambda_6 ht_i + \lambda_7 ipr_i \quad (38.3)$$
$$tert_i = tert_0 + \pi_1 sec_i \quad (38.4)$$

Where pro is the logarithm of labor productivity and it is determined by the logarithm of knowledge spillovers d, the logarithmic difference of labor productivity of a lagged country from a country that leads technological innovation, tert represents tertiary enrollment ratio representing the level of human capital, ipr refers to the degree of intellectual property protection of each country. employment grows at a constant annual rate l. Where y is the total demand, gov is the government expenditure, open is the imports as a share of the GDP, sec is a function of secondary education, ht represents the ratio of high-technology exports on manufactured exports and ipr refers to degree of intellectual property rights protection. Tertiary enrollment, non ICT capital (nict) and ICT capital (ict) are considered endogenous. This fact helps in order to find the relation between them and the method which is used in order to estimate the system is the simultaneous equation 3SLS and the fixed effect model with time dummy variables. Data refers to 29 economies in the 90s and it mostly comes from the World Bank. Table 30 includes the estimations of the system's equations. ICT capital has a positive and statistically significant relation to labor productivity.

Table 30. Estimation of the simultaneous equations model.

	pro	nict	ict	tert
Intercept	-0.882*** (0.096)	3.618*** (0.122)	-0.803*** (0.170)	(0.083) 0.770***
G	0.036*** (0.010)	-	-	-
nict	0.185*** (0.022)	-	-	-
ict	0.104*** (0.029)	-	-	-
tert	0.069*** (0.016)	-	0.393*** (0.053)	-
ipr	-0.048*** (0.013)	-	0.166** (0.079)	-
l	-0.026 (0.048)	3.010*** (0.374)	-	-
y	-	-0.187*** (0.035)	0.488 (0.513)	-
gov	-	-0.056*** (0.020)	0.274*** (0.054)	-
r	-	-	-0.002 (0.029)	-
open	-	-	0.055** (0.027)	-
ht	-	-	-	-
sec	-	0.069*** (0.019)	-	0.770*** (0.083)
Year dummy	yes	yes	yes	yes

Source: Hwan-Joo Seo et al. (2009)

5 Conclusions

This literature review has shown how important is the ICT capital for economic growth. Even sometimes this relationship is not clear, alternative econometric methods have reached important findings. In addition, the VECM method supports this relation is bidirectional. Table 31 reviews the estimations for the output elasticity of ICT. All of them prove that economic growth is affected positively by ICT and most of them show that ICT contribution fluctuates from 0.02% to 0.08% especially according to the most recent investigations. However, Nasab and Aghaei (2009), Hwan-Joo Seo et al. (2009) investigation provide more optimistic results. It is interesting that Hwan-Joo Seo et al. (2009) employ elaborate econometric techniques that appear only once in this literature. The highest value of the coefficient is provided by Barua and Lee (1997) but it is not a robust result as their model estimations for other variables are incorrect. Hanclova et al. (2014) estimations are in growth rates so the coefficient can not be compared to others.

So the positive relation between growth and ICT is provided by many different econometric methods which, however, start from the same growth accounting model. Moreover, even though a strongly positive relation is expected, this is not the case as a part of the effect comes through TFP. TFP refers to technological progress, which is affected by ICT. As a result, the effect of ICT comes through externalities and spillovers. This process is not been captured by ICT coefficient leading to poor results.

On the other side, it is important to report that some researches support that ICT effect is one of a series of positive temporary shocks and it has a non permanent effect on growth (for example, Berndt and Morrison, 1995; Morrison, 1997; Jorgenson and Stiroh, 1999; Jorgenson, 2001; Gordon, 2000). However, more recent research does not prove this result.

Table 31. Review of the results on the ICT coefficient

Research	Econometric methodology	ICT coefficient	Country
Barua and Lee (1997)	OLS	0.683***	US
Stiroh (2002)	OLS	0.051***	US
Barua and Lee (1997)	Translog production function	0.147**	US
O' Mahony and Vecchi (2005)	PMG raw demeaned	0.055** 0.066**	US, UK
Hwan-Joo Seo et al. (2009)	3SLS	0.104***	Cross-country
Nasab and Aghaei (2009)	Fixed effect panel	0.0267***	OPEC
Stiroh (2002)	Static GMM-SYS	0.086***	US
Stiroh (2002)	Dynamic GMM-SYS	0.045**	US
Nasab and Aghaei (2009)	GMM	0.41***	OPEC
Strauss and Samkharadze (2011)	Sys-GMM	0.060 *	EU-15 and US
Hanclova et al. (2014)	PEGLS	0.31398***	EU-14
Stanley et al. (2018)	Meta-regression analysis	0.04***	Cross-country

Semi parametric analysis provides evidence of a non-linear relation between ICT and growth as higher impact of ICT capital on countries with high ICT investment than on those with low ICT investment. This finding goes on with the conventional theory. However Appiah-Otoo and Song (2021) find that higher income countries, which are more likely to invest much money on ICT, are not benefited as much as lower income countries.

Another finding of literature is that the ICT effect is stronger for the US economy than for the EU. While the results for the US prove the relation between ICT and growth, the coefficients of some European countries were very small and either negative or insignificant. Schreyer (2000) suggests that ICT capital in some European countries is concentrated in the services sector which is not very important for the economy. Feldstein (2003), who also supports that growth and ICT are strongly related, highlights the fact that this relation is stronger in the US than in Europe. Moreover he tries to explain this difference by making some claims of his own. He claims that "Incentives and institutional structures were critical ingredients in the rise of productivity." (Feldstein, 2003: 445) In the US the companies, thanks to a supportive and encouraging environment, took the risk of innovation despite people's fear of learning new systems and managers' hesitation of forcing unwanted personnel changes. In Europe such risk was not taken. The author explains that the incentive of these risky decisions was overcompensation (Bonuses and equity-based compensation). The extra income gave employees a motive to work harder and be innovative. Such a thing also did not happen in Europe. While adopting ICT some workers become redundant and it is obligated that they must be discharged. EU legislation makes it more difficult for a firm of a country member to fire employees acting as a disincentive of introducing a new technology.

An interesting aspect on this topic is the effect of the most recent technologies and especially the effect of COVID-19 pandemic which has rapidly increased the use of ICT equipment as every person worked from their homes with their personal computers.

In the end, the productivity paradox of the 90s has been addressed. The usage of more accurate data and more elaborated and advanced econometrics have helped to reveal that ICT has a positive effect on economic growth and as technology improves this contribution will become more and more important and the new technologies will improve the life level around the world.

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