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The Effect of Human Capital on Output Growth in ICT Industries: Evidence from OECD Countries

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Abstract: In this paper we analyse the effects of human capital in fostering output growth in ICT industries using data from a sample of twenty OECD countries over the period 1980-2002. We focus on within country between industry differences and estimate a system of simultaneous equations to account for simultaneous effects of human capital on physical investment and output growth. The results of our econometric analysis suggest that countries with a high human capital stock and high human capital improvement experienced faster output growth in ICT industries. Furthermore, we find that past country level educational attainment reflected in the human capital stock and human capital accumulation over the analysed period had a direct positive and significant effect on physical capital investment. In addition, we found that in countries with an *ex-ante* high human capital stock and in countries with high human capital accumulation, ICT producing manufacturing and ICT using services grew relatively faster.

Key words: Human capital, ICT industries, Economic growth

JEL classification: E62, F43, O33

The Effect of Human Capital on Output Growth in ICT Industries: Evidence from OECD countries*

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1 Introduction

Information and communication technologies (ICT) play a central role in the transition to knowledge - based economies. In this paper we analyse the effects of human capital in fostering output growth in ICT manufacturing and services in a sample of twenty OECD countries over the period 1980-2002. We focus on within country between industry differences and control for country and industry specific effects and a set of macroeconomic variables.

The question whether human capital fosters economic growth, in particular the output growth in ICT industries is interesting and relevant for both research and policy. First, notwithstanding a well-established theoretical literature showing the positive effects of human capital on economic growth, existing empirical evidence is mixed.

Second, ICT are at the core of the knowledge driven economy and there is growing evidence suggesting that ICT-linked knowledge, innovation and technological changes are strong determinants of growth differentials and the ability of countries to benefit from globalization. While earlier studies have found little evidence about a link between ICT and output growth, more recent studies point to a positive effect of ICT investment on output growth (Oliner and Sichel, 2000; Daveri, 2001, Roeger, 2001; van Ark, 2001; Pilat and Lee, 2001; OECD, 2001).

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The renewed Lisbon Strategy agreed in March 2005 put a special emphasis on the role ICT can play in boosting growth, competitiveness and cohesion in the European Union (EU). A large amount of EU expenditure over the period 2007-2013 has been allocated to ICT investment. Furthermore, the ICT strategy at the EU level outlined in the i2010 Communication of the EU Commission points to ICT investment, research and use as a main explanation for differences in economic performance among industrialised countries.

Third, our research about the relationship between human capital and ICT growth is relevant for education policy in developed countries.

In comparison to existing literature, the novelty of this paper is threefold. First, we link human capital to ICT output growth by focusing on within country, between industry differences. We employ a cross-country, cross-industry analysis and control for country- and industry-specific effects which is less subject to criticism about an omitted variable bias and model specification. Second, we investigate the effect of human capital on ICT growth using measures for both the stock of human capital and accumulation of human capital. Fifth, we distinguish between ICT producing and ICT using manufacturing and services.

The main message of this paper is that in the developed countries, human capital is an important factor driving the output growth in ICT industries. Specifically, in countries with an *ex-ante* high human capital stock, and in countries with a high human capital accumulation, ICT industries grew relatively faster. Furthermore, human capital stock and human capital improvement had a positive and significant effect on physical capital investment. We also distinguished between ICT producing and ICT using manufacturing and services and found that human capital was an important driving output growth in ICT producing manufacturing and ICT using services.

The remainder of this paper is organised as follows. In Section 2 we discuss the related theoretical and empirical literature. Further, in Section 3 we outline our empirical strategy, model specifications and explain how we test and account for potential econometric issues. Section 4 present the results of our empirical analysis. Finally, we conclude in Section 5.

2 Related Theoretical and Empirical Literature

There is a well-established theoretical literature on the effect of human capital on growth initiated by Becker (1964) and followed by the seminal papers of Nelson and Phelps (1966), Lucas (1988), Romer (1990) and Mankiw, Romer and Weil (1992).

Two approaches can be distinguished in the theoretical literature[1]. The first strand of literature focuses on the *stock* of human capital as an explanation of cross-country growth differentials as suggested by Nelson and Phelps (1966). The second approach looks at human capital as an input factor in a production function as in Lucas (1988) and points to the *accumulation* of human capital as the main factor driving growth differentials among countries.

The theoretical literature indicates different channels through which human capital affects economic growth. Nelson and Phelps (1966) show that high levels of human capital facilitate the adoption of new technologies. In contrast to this view, Lucas (1988) focuses on skill acquisition as an input in an aggregate production function. Romer (1990) assumes that both the stock as well as the growth of human capital generate ideas for new designs and goods which in turn drive endogenously physical capital investment and growth. Mankiw, Romer and Weil (1992) include physical capital and human capital investment rates (as ratios of GDP) as distinct arguments in an extended Solow model.

Most empirical analyses use education attainment as a proxy for human capital and investigate the relationship between the level of education or education improvement and output growth at country level. In most of the existing studies model specifications explain the growth of GDP or GDP per capita with a series of macroeconomic variables including educational attainment.

The results obtained with cross-country growth regressions are mixed. While Romer (1990), and Benhabib and Spiegel (1994) found a positive effect of the schooling level on output growth, Cohen and Soto (2001) found no link. The same mixed evidence has been found in the case of the relationship between improvements in education and growth. In contrast to a significant positive correlation between improvements in education and growth found by Temple (1999), Cohen and Soto

[1] For a detailed discussion of these two theoretical approaches see Aghion and Howitt (1998)

(2001), de la Fuente and Domenech (2001, 2005), no effect of schooling improvement on growth is found in other studies (Benhabib and Spiegel, 1994; Barro and Sala-i-Martin, 1995; Casseli, Esquivel and Lefort, 1996). Furthermore, Topel (1999) and Lindhal (2001) find a positive effect of the education level as well as of education improvement on economic growth.

Cross-country growth regressions have several shortcomings (no controls for unobserved heterogeneity, limited degrees of freedom, among others). Analysis at industry level across countries can correct for these limitations by exploiting the within country variation between industries. Rajan and Zingales (1998) use a cross-country cross-industry analysis to examine whether financial development fosters economic growth. They find that industries that are dependent on external finance grew faster in countries with more developed financial markets. Using a similar analysis at industry level in a large sample of countries, Ciccone and Papaioannou (2006) find that industries that are more dependent on human capital grew relatively faster in countries that initially hade more human capital.

Following the seminal paper by Nelson and Phelps (1966), a large empirical literature has focused on the relationship between human capital and new technology adoption. Chun (2003) provide empirical evidence from the US over 1960-1996 showing that highly educated workers were more likely to implement new technologies such as information technology. The adoption and use of IT accounted for a large proportion of the increase in the demand for educated workers over the period 1970-1996.

Bartel and Sicherman (1999) find a positive correlation between the education premium of workers and technological change at industry level. Caselli and Coleman (2001) find that the educational attainment was an important determinant of the level of investment in computers in a sample of OECD countries over the period 1970-1990.

Firm-level evidence suggests that firms using advanced technology employ more skilled workers. Doms et al (1997) use plant-level data from the US and find a positive correlation between the education of workers and the use of new technology. Furthermore, they find that plants that invested relatively more in computing equipment had a higher increase in the share of non-production workers. Similar evidence supporting the hypothesis that the presence of highly-skilled workers fosters innovation and facilitates the ICT adoption and use at firm level was found in other studies (Arvanitis, 2005; Bresnahan et al., 2002, Fabiani et al., 2005; Falk, 2005; Bayo-Moriones and Lera-López).

ICT have become a general purpose technology in developed economies (Carlsson, 2004) and they play a central role in the transition to the knowledge based economy ("the digital economy"). While early research found ICT *producing* industries to be an important factor of economic growth, more recent research found a significant contribution to economic growth from ICT *using* industries. Carlsson (2004) and Hollestein (2004) find evidence suggesting that ICT had a positive effect on economic growth via new products and services and new organisation methods.

3 Empirical Strategy and Model Specifications

In this paper we examine the relationship between human capital at country level and the output growth in ICT industries. Our model specification exploits the within country between industry variation following the methodology used by Rajan and Zingales (1998) and Ciccone and Papaioannou (2006). On the basis of the theoretical and empirical literature discussed above, we test the hypothesis that ICT industries grew faster in countries with an initial high stock of human capital and greater improvement in human capital.

Romer (1990) argues that both the stock and the growth of human capital generate ideas for new designs and goods which in turn drive physical capital investment and economic growth. There is also the possibility that the accumulation of human capital could be endogenous as countries with a high income level or fast growing economies are able to allocate a higher proportion of their resources to education (Gemmel, 1996).

To account for both the direct and indirect effects (i.e. via physical capital investment) of human capital stock and accumulation on industrial output growth while controlling for potential simultaneity and endogeneity problems we specify a system of simultaneous equations as follows:

Primary equation:

$$\Delta y_{i,k,T} = \lambda_i + \mu_k + \alpha_1(hc_{i,t_0} * ict) + \alpha_2(\Delta hc_{i,T} * ict) + \alpha_3(inv_{i,T} * ict) + \alpha_4(lf_{i,t_0} * ict) + \\ + \alpha_5(\Delta lf_{i,T} * ict) + \alpha_6(op_{i,T} * ict) + \alpha_7(share_{i,k,t_0}) + \varepsilon_{i,k}$$

Structural equations:

$$inv_{i,T} * ict = \lambda_i + \beta_1(hc_{i,t_0} * ict) + \beta_2(\Delta hc_{i,T} * ict) + \beta_3(gdp_{i,t_0} * ict) + \beta_4(lf_{i,t_0} * ict) + \\ + \beta_5(\Delta lf_{i,T} * ict) + \omega_{i,k}$$

$$\Delta hc_{i,T} * ict = \lambda_i + \delta_1(hc_{i,t_0} * ict) + \delta_2(\Delta hc_{i,T-1} * ict) + \delta_3(inv_{i,T} * ict) + \delta_4(gdp_{i,t_0} * ict) + \\ + \upsilon_{i,k}$$

In the primary equation, the dependent variable ($\Delta y_{i,k,T}$) is a measure of industry output growth, specifically, the average annual growth rate of the real gross value added at industry (k) level within country (i) over the analysed period (T). The main explanatory variables are the human capital stock (*hc*) and human capital accumulation (Δhc) interacted with a dummy variable (*ict*) which takes the value 1 if industry *k* is an ICT industry and 0 otherwise. Industries are grouped in ICT and non-ICT industries following the taxonomy proposed by Robinson et al (2003). The industry classification according to this taxonomy is given in Appendix A1.

Our sample includes 20 countries[2] and 54 industries[3]. The data set covers the period 1980 until 2002 resulting in a number of 1080 observations. Details about data sources are given in Appendix A2 and summary statistics of the main variables are shown in Tables 1-4.

The stock of human capital is measured as average years of schooling at a point in time taken from Cohen and Soto (2001). The human capital stock variable used in regressions is the natural logarithm of the average years of schooling at country level in 1980 (hc_{i,t_0}). The human capital improvement is measured by the growth in the average years of schooling or educational attainment over the analysed period ($\Delta hc_{i,T}$).

We control for country specific (λ_i) and industry specific (μ_k) growth effects. Country specific growth effects include unobserved factors affecting economic

[2] Australia Austria, Belgium, Canada, Denmark, Spain, Finland, France, Greece, Ireland, Italy, Japan, Netherlands, Norway, Portugal, Sweden, Germany, United Kingdom, United States and South Korea.

[3] See Appendix A1

growth at country level. Industry specific growth effects include unobserved industry characteristics.

Other control variables include:

- the share of each industry in total real gross value added at country level in the initial year ($share_{i,k,t_0}$)
- gross domestic product per working age population at country level in the initial year (gdp_{i,t_0})
- the ratio of physical capital investment to GDP at country level, average over the analysed period ($inv_{i,T}$)
- labour force at country level in the initial year (lf_{i,t_0})
- labour force growth at country level over the analysed period $(\Delta lf_{i,T})$
- the ratio of trade to GDP (openness measure) at country level over the analysed period $(op_{i,T})$

$\varepsilon_{i,k}$ is the error term.

If in the primary equation, $\alpha_1 > 0$, output growth in ICT industries was relatively faster in countries with an initial high human capital stock. Furthermore, if $\alpha_2 > 0$, ICT output growth was relatively faster in countries with high human capital accumulation.

In the structural equations for investment, $inv_{i,T}$ denotes the average over the analysed period (T) of the physical capital investment to GDP ratio at country level. Initial human capital stock, human capital growth over the analysed period, initial labour force stock, labour force growth over the period, GDP per working age population at country level in 1980 as well as country specific effects are used as explanatory variables.

In the structural equations for human capital accumulation, we use the initial human capital stock, lagged human capital growth, GDP per working age population at country level in 1980, physical capital investment as well as country specific effects as explanatory variables for human capital accumulation.

We estimate the system of the three simultaneous equations discussed above using a three-stage-least square estimator (3SLS). The results are shown in Table 5.

Further, we distinguish between four categories of ICT industries following the taxonomy[4] proposed by Robinson et al (2003):

- ict_{pm}: 1 if industry is ICT producing manufacturing and 0 otherwise
- ict_{ps}: 1 if industry is ICT producing services and 0 otherwise
- ict_{um}: 1 if industry is ICT using manufacturing and 0 otherwise
- ict_{us}: 1 if industry is ICT using services and 0 otherwise

The results of the nine simultaneous equations system are shown in Table 6.

4 Empirical Results

Tables 1 – 4 show summary statistics of the main variables included in our model specifications. The average annual output growth across all countries was 3.8 per cent over the analysed period. Average output growth across ICT industries was 5.8 per cent compared to 2.0 per cent for non-ICT industries. Inspection of the four ICT industry classifications which combine to make up the ICT industry grouping shows ICT producing industries have recorded the strongest performance with an average annual output growth rate of 14.0 per cent for ICT producing manufacturing and 7.4 per cent for ICT producing services. ICT using manufacturing and services have grown notably slower with average growth rates of 1.8 per cent and 3.9 per cent respectively. In terms of average output growth, Korea and Ireland have outperformed all other countries across all ICT producing and ICT using defined industry groupings (see Table 2).

The above output growth summary statistics give some indication to the increasing importance of the ICT industry sectors to a country's economic development. It suggests the emphasis the Lisbon Agenda places on capturing, promoting and sustaining the dynamism associated with the ICT industry sectors is warranted.

Human capital measured in terms of average years of schooling is unsurprisingly high (10.0 years) for the sample in 1980 given that the countries are relatively well

[4] Details about the ICT taxonomy are given in Appendix A1.

developed. Portugal and Spain had the lowest educational attainment levels whilst Germany and Australia recorded the highest levels (see Table 3).

Those countries with the lowest levels of educational attainment tended to experience the highest rates of human capital accumulation over the full period (correlation between the two series is -0.85).

The average country level investment ratio was 23.1 per cent. Table 4 presents a cross-country summary of the investment ratio and average labour force growth by country. Japan and Korea emerge as the countries with the highest investment ratios, in excess of 30 per cent. The average annual labour force growth was 1.0 per cent for the full period of investigation.

Table 5 shows the 3 SLS estimates of the simultaneous effects of human capital measures on physical capital investment and output growth. The results shown in column 1 indicate that in countries with an initial high human capital stock, output in ICT industries grew relatively faster. Furthermore, in countries with a high capital accumulation, ICT industries grew relatively faster. Country and industry specific effects were jointly significantly different from zero.

In addition, as shown in columns 2-5, we find that human capital stock and human capital accumulation had a positive effect on physical capital investment at country level. This result is in line with Romer (1990).

Columns 6-9 show the estimates of the structural equation for human capital accumulation. We find that the initial human capital stock, human capital accumulation over 1970-1980, and physical capital investment were positively associated with human capital accumulation over 1980-2002.

Further, we re-estimate the model and distinguish between ICT producing and ICT using manufacturing and services. The results shown in column 1 of Table 6 indicate that countries with a high initial stock of human capital and high human capital accumulation experienced faster output growth in ICT producing manufacturing and ICT using service industries.

The estimates obtained in the investment equations (columns 2-5) suggest that human capital stock and human capital accumulation at country level had a direct positive and highly significant effect on physical capital investment.

Over four fifths of the variation in industrial output growth is explained by our model.

5 Summary and Conclusions

In this paper we investigated the effects of human capital on the output growth in ICT industries using data from a sample of twenty OECD countries and 54 industries over the period 1980-2002. We focused on within country, between industry differences and controlled for country and industry specific effects and a set of macroeconomic variables. Further, we distinguished between ICT producing and ICT using manufacturing and services. In addition, we analyse the effects of both human capital stock and human capital accumulation.

Our model specifications accounted for endogeneity and the simultaneity effects in the relationship between human capital and output growth. The results of our econometric analysis suggest that in the OECD countries, past educational attainment reflected in the human capital stock and in human capital improvement affected the output growth in ICT industries. Countries with an ex-ante high human capital stock and countries with a high human capital accumulation experienced a faster output growth in ICT industries. Following the recent literature on ICT, it is interesting to distinguish between ICT producing and ICT using manufacturing and services. In this respect, we found that on average, other things equal, in countries with an *ex-ante* high human capital stock, ICT producing manufacturing and ICT using services grew faster relative to non-ICT industries. Similarly, on average, other things equal, in countries with high human capital accumulation, ICT producing manufacturing and ICT using services grew faster in comparison with non-ICT industries. Furthermore, we find that human capital stock and human capital improvement had a positive and significant effect on physical capital investment.

Our findings indicate that in developed countries human capital is an important factor driving the ICT industries growth. This suggests that education policy aimed at human capital improvement is likely to be complementary to policy supporting the diffusion of ICT.

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Appendix A1

ICT Taxonomy

The source of this ICT taxonomy is Robinson et al (2003). On the basis of the latest OECD STAN Database on National Accounts, industries are classified in the following seven categories depending on whether they produce ICT goods or services, and whether they use intensively ICT or they do not use ICT intensively.

***1. ICT Producing - Manufacturing* (ICTPM)**

Office machinery (30); Insulated wire (313); Electronic valves and tubes (321); Telecommunication equipment (322); Radio and television receivers (323); Scientific instruments (331).

2. ICT Producing – Services (ICTPS): Communications (64); Computer &related activities (72).

***3. ICT Using – Manufacturing* (ICTUM)**

Clothing (18); Printing & publishing (22); Mechanical engineering (29); Other electrical machinery & apparatus (31-313); Other instruments (33-331); Building and repairing of ships and boats(351); Aircraft and spacecraft (353); Railroad equipment and transport equipmentnec (352+359);Furniture, miscellaneous manufacturing; recycling (36-37).

***4. ICT Using – Services* (ICTUS)**

Wholesale trade and commission trade, except of motor vehicles and motorcycles (51); Retail trade, except of motor vehicles and motorcycles; repair of personal and household goods (52); Financial intermediation, except insurance and pension funding (65); Insurance and pension funding, except compulsory social security (66); Activities auxiliary to financial intermediation (67); Renting of machinery & equipment (71); Research & development (73); Legal, technical & advertising (741-3).

***5. Non-ICT Manufacturing* (NICTM)**

Food, drink & tobacco (15-16); Textiles (17); Leather and footwear (19); Wood & products of wood and cork (20); Pulp, paper & paper products (21); Mineral oil refining, coke & nuclear fuel (23); Chemicals (24); Rubber & plastics (25); Non-metallic mineral products (26); Basic metals (27); Fabricated metal products (28); Motor vehicles (34).

*6**. Non-ICT Services*** **(NICTS)**

Sale, maintenance and repair of motor vehicles and motorcycles; retail sale of automotive fuel (50); Hotels & catering (55);Inland transport (60); Water transport (61); Air transport (62); Supporting and auxiliary transport activities; activities of travel agencies (63); Real estate activities (70); Other business activities, nec (749); Public administration and defence; compulsory social security (75); Education (80); Health and social work (85); Other community, social and personal services (90-93); Private households with employed persons (95); Extra-territorial organizations and bodies (99).

***7. Non-ICT Other* (NICTO)**
Agriculture (01); Forestry (02); Fishing (05);Mining and quarrying (10-14); Electricity, gas and water supply (40-41); Construction (45)

In this paper we combine NICTM, NICTS, NICTO as one group (non-ICT industries).

Appendix A2

Data Sources

Variables	**Description**	**Source**
Dependant Variable		
$\Delta \mathbf{y}_{i,k,T}$	Average annual growth in real gross value added in country i, industry k, 1980-2002	www.ggdc.net
Explanatory Variables		
Human capital variables		
$\mathbf{hc}_{i,t0}$	The natural logarithm of average number of years of schooling in 1980	Cohen and Soto (2001)
$\Delta \mathbf{hc}_{i,T}$	Growth in average number of years of schooling between 1980-2000	Cohen and Soto (2001)
Control variables		
$\mathbf{share}_{i,k,t0}$	The share of industry k in total gross value added at country level in 1980	www.ggdc.net
$\boldsymbol{gdp}_{i,\ t0}$	GDP per working age population, 1980	International Financial Statistics, IMF and OECD
$\boldsymbol{inv}_{i,T}$	Average investment ratio over 1980-2002	Penn World Tables 6.2
$\boldsymbol{lf}_{i,T}$	Initial Stock of labour force in 1980	OECD
$\Delta \boldsymbol{lf}_{i,T}$	Average annual labour force growth, 1980 -2002	OECD
$\boldsymbol{op}_{i,T}$	Average ratio of exports and imports to real GDP, 1980-2002	Penn World Tables 6.2

Table 1: Summary Statistics

Variables	Mean	Std. Dev.	Min	Max
Dependant variable				
Average annual real gross value added growth rate, 1980-2002 (%)	3.8	7.2	-14.4	51.3
Human capital measures				
Average years of schooling, 1980	10.0	1.8	5.5	12.6
Average years of schooling, 2000	11.5	1.5	7.2	13.1
Human capital accumulation, 1980-2000 (%)	14.3	8.4	2.3	30.3
Other control variables				
Industry share in total gross value added at country level, 1980 (%)	1.8	2.2	0.0	15.2
GDP per working age population (thousand US dollars)	15.3	6.0	3.2	24.7
Investment to GDP ratio (%)	23.0	3.9	17.2	35.2
Average annual labour force growth (%)	1.0	0.6	0.1	2.0

Table 2: Average annual real gross value added growth rate by country and sector, 1980-2002 (%)

Country	Total	ICT	Non ICT	ICTUM	ICTPM	ICTPS	ICTUS
Australia	2.4	3.0	1.8	1.0	2.0	8.7	4.6
Austria	4.1	6.3	2.1	1.9	15.6	7.7	3.9
Belgium	3.0	4.6	1.5	1.6	13.1	3.9	1.9
Canada	2.6	3.2	2.2	1.2	4.5	6.1	3.6
Denmark	3.5	5.5	1.9	1.0	14.7	9.0	2.7
Spain	3.7	5.5	2.1	3.3	12.2	6.7	2.8
Finland	4.4	6.9	2.2	1.3	19.1	7.4	3.8
France	3.2	5.7	1.1	1.5	16.6	5.6	2.2
Greece	3.4	5.3	1.8	1.3	12.2	8.4	3.9
Ireland	6.5	10.1	3.5	4.2	25.0	8.2	6.0
Italy	3.1	5.0	1.4	1.3	13.4	6.0	2.7
Japan	3.6	6.6	1.0	1.7	16.9	6.1	4.7
Netherlands	3.5	5.3	2.0	1.7	12.5	7.1	3.4
Norway	2.4	3.7	1.2	-1.4	11.3	7.7	2.6
Portugal	4.4	6.7	2.5	3.6	15.2	6.6	3.8
Sweden	3.2	5.1	1.5	0.6	12.5	5.6	4.6
Germany	2.6	4.6	0.8	0.3	12.6	6.6	3.0
United Kingdom	3.1	5.1	1.4	0.4	13.5	7.8	3.4
United States	3.8	5.4	2.4	0.5	14.0	6.9	4.2
South Korea	9.4	13.1	6.1	8.3	23.7	16.5	9.8
Mean	3.8	5.8	2.0	1.8	14.0	7.4	3.9

Table 3: Human capital variables by country

Countries	**Human capital stock 1980**	**Human capital accumulation (%) 1980-2000**
Australia	12.2	7.0
Austria	10.3	10.3
Belgium	9.2	15.9
Canada	11.5	12.0
Denmark	11.0	10.0
Spain	7.4	24.3
Finland	9.4	20.7
France	9.3	13.8
Greece	7.7	24.8
Ireland	8.9	12.8
Italy	7.9	26.0
Japan	11.1	11.8
Netherlands	10.2	9.8
Norway	11.5	7.6
Portugal	5.5	26.7
Sweden	11.2	4.0
Germany	12.6	2.3
United Kingdom	11.5	12.5
United States	12.1	3.5
Korea	9.1	30.3
Obs.	20	20
Mean	10.0	14.3
Standard Deviation	1.8	8.4
Minimum	5.5	2.3
Maximum	12.6	30.3

Table 4: Average investment ratio and average annual labour force growth by country

	Average Investment to GDP Ratio (%)	Average Annual Labour Force Growth Rate (%)
Countries	**1980-2002**	**1980-2002**
Australia	23.8	1.7
Austria	23.5	1.0
Belgium	21.4	0.4
Canada	23.3	1.5
Denmark	20.5	0.2
Spain	22.3	1.4
Finland	25.9	0.2
France	22.3	0.6
Greece	20.7	1.3
Ireland	20.7	1.7
Italy	21.6	0.3
Japan	30.8	0.7
Netherlands	21.6	1.9
Norway	24.8	0.9
Portugal	21.0	0.9
Sweden	20.2	0.1
Germany	23.2	1.5
United Kingdom	17.2	0.3
United States	19.8	1.3
South Korea	35.2	2.0
Count	20	20
Mean	23.0	1.0
Standard Dev.	3.9	0.6
Minimum	17.2	0.1
Maximum	35.2	2.0

Table 5: The effect of human capital on ICT output growth, 3SLS estimates

	Primary Equation	Structural equations	
Dependent variable	$\Delta y_{i,k,T}$	$inv_{i,T}$*ict	$dhc_{i,T}$*ict
$hc_{i,t0}$*ict	0.194***	0.226***	-0.499***
	(0.070)	(0.006)	(0.023)
$dhc_{i,t0}$*ict[(a)]	0.634***	0.429***	0.123***
	(0.195)	(0.009)	(0.036)
$share_{i,k,t0}$	0.088		
	(0.083)		
$lf_{i,t0}$*ict	0.001	-0.0004***	
	(0.003)	(0.0002)	
$dlf_{i,t0}$*ict	0.447	0.220***	
	(0.571)	(0.052)	
$inv_{i,T}$*ict	-0.224		2.131***
	(0.254)		(0.097)
$op_{i,T}$*ict	0.0002*		
	(0.0001)		
$gdp_{i,t0}$*ict		-0.036***	0.081***
		(0.001)	(0.004)
Obs	1080	1080	1080
R^2	0.8208	0.9921	0.9234
Country Fixed Effects	yes	Yes	Yes
Industry Fixed Effects	yes	No	No

Test for joint significance of country and industry fixed effects: $\chi^2(110) = 4685.09.31$Prob > $\chi^2 = 0.0000$

Std errors are in parentheses. *** Significance at the 1% level, ** significance at the 5% level, * significance at the 10% level.

(a) ‘Lagged’ growth rate of human capital accumulation over the period 1970-1980 is used as an instrument in the human capital accumulation equations.

Table 6: The effect of human capital on ICT output growth, 3SLS estimates									
	Primary equation	**Structural equations**							
	$\Delta y_{i,k,T}$	inv_i*ict_{pm}	inv_i*ict_{ps}	inv_i*ict_{um}	inv_i*ict_{us}	dhc_i*ict_{pm}	dhc_i*ict_{ps}	dhc_i*ict_{um}	dhc_i*ict_{us}
hc_i*ict_{pm}	0.410*** (0.114)	0.212*** (0.006)				-0.469*** (0.027)			
hc_i*ict_{ps}	-0.001 (0.185)		0.208*** (0.006)				-0.457*** (0.028)		
hc_i*ict_{um}	0.037 (0.097)			0.214*** (0.006)				-0.478*** (0.025)	
hc_i*ict_{us}	0.214** (0.1)				0.213*** (0.006)				-0.480*** (0.025)
dhc_i*ict_{pm} [(a)]	1.371*** (0.319)	0.407*** (0.010)				0.210*** (0.047)			
dhc_i*ict_{ps} [(a)]	-0.033 (0.518)		0.402*** (0.010)				0.239*** (0.052)		
dhc_i*ict_{um} [(a)]	0.224 (0.27)			0.410*** (0.009)				0.186*** (0.051)	
dhc_i*ict_{us} [(a)]	0.582** (0.28)				0.408*** (0.010)				0.183*** (0.045)
inv_i*ict_{pm}	-0.820** (0.415)					2.082*** (0.138)			
inv_i*ict_{ps}	0.746 (0.674)						2.044*** (0.152)		
inv_i*ict_{um}	0.099 (0.35)							2.116*** (0.153)	
inv_i*ict_{us}	-0.310 (0.367)								2.135*** (0.129)
Obs	1080	1080	1080	1080	1080	1080	1080	1080	1080
R^2	0.801	0.988	0.986	0.988	0.987	0.876	0.870	0.882	0.877
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	No	No	No	No	No	No	No	No
Test for joint significance of country and industry fixed effects: $\chi^2(224) = 3721.31$ Prob > $\chi^2 = 0.0000$ Hansen-Sargan over-identification test: $\chi^2(588) = 540.438$ Prob > $\chi^2 = 0.9202$									

Notes:

Std errors are in parentheses. *** Significance at the 1% level, ** significance at the 5% level, * significance at the 10% level.

[(a)] 'Lagged' growth rates of human capital accumulation over the period 1970-1980 are used as instruments in the human capital accumulation equations.

The primary equation includes the following control variables: the share of each industry in total real gross value added in the initial year; labour force stock in the initial year, labour force growth over the analysed period, the ratio of investment to GDP, average over the analysed period; the ratio of trade to GDP (openness measure) at country level over the analysed period. The structural equations for investment include gross domestic product per working age population in the initial year; labour force stock in the initial year; labour force growth over the analysed period. The structural equations for human capital accumulation include gross domestic product per working age population and the ratio of investment to GDP, average over the analysed period. The estimates not shown above are available from the authors.

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