RUHR ECONOMIC PAPERS

Chuan Liu
Marianne Saam

ICT and Productivity Growth within Value Chains

RUHR UNIVERSITÄT BOCHUM RUB

#828

Imprint

Ruhr Economic Papers

Published by

RWI – Leibniz-Institut für Wirtschaftsforschung
Hohenzollernstr. 1-3, 45128 Essen, Germany

Ruhr-Universität Bochum (RUB), Department of Economics
Universitätsstr. 150, 44801 Bochum, Germany

Technische Universität Dortmund, Department of Economic and Social Sciences
Vogelpothsweg 87, 44227 Dortmund, Germany

Universität Duisburg-Essen, Department of Economics
Universitätsstr. 12, 45117 Essen, Germany

Editors

Editorial Office

Ruhr Economic Papers #828

Responsible Editor: Thomas Bauer

ISSN 1864-4872 (online) – ISBN 978-3-86788-961-2

Ruhr Economic Papers #828

Chuan Liu and Marianne Saam

ICT and Productivity Growth within Value Chains

Bibliografische Informationen der Deutschen Nationalbibliothek

The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available on the Internet at **http://dnb.dnb.de**

RWI is funded by the Federal Government and the federal state of North Rhine-Westphalia.

http://dx.doi.org/10.4419/86788961
ISSN 1864-4872 (online)
ISBN 978-3-86788-961-2

Chuan Liu and Marianne Saam[1]

ICT and Productivity Growth within Value Chains

Abstract

To what extent have economies become better off because of the diffusion of information and communication technologies (ICT)? We analyze this question based on a growth accounting approach at the level of final output. This approach traces productivity improvements not within sectors but within value chains. It allows judging in a better way to what extent more or better products have become available to final users, in particular consumers, as a result of the diffusion of ICT. A main result is that more than half of the productivity gains related to ICT capital deepening for manufactured goods are contributed by upstream industries. The major part of this contribution is domestic rather than foreign. Moreover, the high sectoral growth in total factor productivity (TFP) in the ICT sector contributes only moderately to TFP growth in non-ICT value chains via the use of intermediates.

JEL-Code: E22, F62, O47

Keywords: ICT; economic growth; productivity; value chains; growth accounting

November 2019

1 Both RUB. – We gratefully acknowledge financial support by the Hans Boeckler foundation within the project "Growth Potential of the Digital Transformation". We thank Wen Chen for generously sharing his expert knowledge on the WIOD data and on programming input-output analysis and Thomas Niebel for helpful advice. Nadine Schaarschmidt and Junwen Zhuang provided excellent research assistance. Seminar participants at the RGS Doctoral Conference 2019 gave valuable comments. All errors remain our own. *- All correspondence to: Marianne Saam, Ruhr University Bochum (RUB), Faculty of Management and Economics, Center for Entrepreneurship, Innovation and Transformation (CEIT), 44801 Bochum, Germany, e-mail: marianne.saam@rub.de*

1 Introduction

The diffusion of digital technologies has transformed the economy and increased productivity, which raises incomes and product quality and lowers product prices. During the first decades of the 21st century, technological transformation seems to be accelerating again while the productivity numbers are not. In order to better understand the potential of further digital transformation ahead, it is useful to turn back to the period of the Internet boom and to deepen our understanding of the productivity growth at that time. While the Solow paradox, according to which the productivity effects of information and communication technologies (ICT) were not visible in statistics, remains a popular saying, the research undertaken since Solow's observation in the late 1980s has gained solid evidence that many sectors and countries experienced visible, though not always dramatic productivity growth related to the diffusion of ICT. At the sectoral level, this ICT-related growth occurs in two forms, first, in the form of more and better ICT capital used in all sectors of the economy and, second, in the form of more productive use of capital and labor in the ICT sector itself thanks to new inventions ("Moore's law") and other improvements.

Many studies on the productivity effects of ICT were conducted at the industry level. Some of the industries experiencing productivity growth through digital transformation, such as knowledge-intensive business services, deliver a high share of intermediate products. Intermediate products do not directly benefit final users (which are consumers, government, and firms buying capital goods) but are in turn used to produce something else. In sum, sector-level results do not tell directly which are the goods and services that final users can buy more cheaply or in better quality because of technological progress. Anecdotal evidence suggests that a lot of progress has taken place in the domain of digital goods and services being sold directly to final users. Nowadays, consumers are using cell phones, Internet, online on-demand music and movies etc. One particular aspect is that an increasing amount of services is freely available on the web. This phenomenon is not considered in the paper. We rather consider the goods and services that are part of gross domestic product (GDP). In discussing the digital strength of a country, the public debate often focuses on large ICT-producing firms such as Microsoft. For the aggregate effect of digital transformation on GDP growth, the indirect effect, however, can be expected to be even more important (Oulton, 2012). This is the effect that the use of digital goods and services has on the production of other, non-digital final goods and services such as food, cars, travel and more.

The analytical framework to consider the indirect effect investment and progress in ICT have on the goods and services finally produced in a country is the framework of global value chains. A global value chain is the chain of value creating activities that take place in different sectors and countries to create a particular final product in a certain country, e.g. a car in Germany. We apply the technique of growth accounting at the level of global value chains in order to investigate how much the productivity increase in the ICT sector and the use of ICT capital at different stages of the value chain contribute to labor productivity growth in the production of final goods. The notion of labor input includes here labor used directly and indirectly in the production of the final good.

We need global data in order to analyze global value chains, which are available in the World Input-Output Database (WIOD). Data quality varies across countries. Despite the growing interconnectedness of industries, large shares of value creation still take place at the final stage of a value chain. For this reason, we focus in the empirical analysis on final products produced in countries for which we have relatively good data.

We find that the aggregate contribution of ICT capital deepening to productivity growth in value chains is similar for value chains of non-ICT goods and non-ICT services. More than half of the productivity gains related to ICT capital deepening for manufactured goods are contributed by upstream industries. The majority of this contribution is domestic rather than foreign. The most important upstream sectors contributing to productivity growth in value chains are business and financial services and distribution services. The high sectoral TFP growth in the ICT sector contributes only moderately to growth in total factor productivity in non-ICT value chains via the use of intermediates.

2 Previous Literature

Most previous studies on macroeconomic effects of ICT were carried out at the sector level. While the results of growth accounting and econometric studies differ to some degree, a rough consensus among these studies was established by Cardona et al. (2013). In a survey of a large number of papers, they find that ICT capital deepening, which is the increase of ICT capital per unit of labor input, has contributed visibly to labor productivity growth at the sectoral level. The median increase of labor productivity associated with a one percent increase in ICT capital per worker is about 0.05 to 0.06 percent. A further effect is that total factor productivity tends to grow faster in ICT-intensive industries. This effect, however, is more difficult to pin down with precision. While both, econometric estimation and growth accounting can be used for such studies, the method of growth accounting has been more popular at the sectoral level while econometric estimation is used more frequently at the firm level.

In contrast to previous studies, we investigate the productivity effects of ICT at the level of value chains. Although the method of growth accounting at the level of value chains is not new (Hulten, 1978; Aulin-Ahmavaara, 1999), it has so far rarely been applied, probably because the data demands at this level are much higher. Another reason may be that sector-level evolutions are in the focus of policies targeted at firm-level productivity. Better data to investigate global value chains have become available with the World Input-Output Database (WIOD), which was first developed in a project of the 7th EU Framework Programme (Timmer et al., 2015). The data have been used in studies by Timmer (2017) and Gu and Yan (2017) on which we directly build. These studies, however, do not focus on ICT-related productivity growth. To our knowledge, our study is the first to focus specifically on effects of ICT on productivity growth at the level of value chains.

3 Growth Accounting Method

Following Timmer (2017), we consider an input-output framework with N countries and S sectors.[1] This gives $S \times N$ different value chains for the production of final products. Product markets are assumed to clear, which means that the total quantity of the product produced in a particular sector and country equals the final use for this product in all countries plus the intermediate input use in all country-sectors:

$$y_i(s) = \sum_j \sum_t m_{ij}(s,t) + \sum_j f_{ij}(s). \tag{1}$$

where $y_i(s)$ is the gross output of sector s of country i, $f_{ij}(s)$ the output from this sector for final use in country j, $m_{ij}(s,t)$ the output used as intermediate input by sector t of country j. Let $\mathbf{y}$ be the stacked $SN \times 1$ vector of all gross outputs and $\mathbf{f}$ the stacked $SN \times 1$ vector of all final outputs from each country-sector. The global intermediate input coefficients matrix $\mathbf{A}$ has the dimension $SN \times SN$ and its individual elements are $a_{ij}(s,t) = m_{ij}(s,t)/y_j(t)$. The elements represent the output from sector s of country i used as intermediate input in sector t of country j, expressed per unit of gross output of sector t in country j.

The stacked market clearing conditions from (1) can be now written in matrix notation:

$$\mathbf{y} = \mathbf{A}\mathbf{y} + \mathbf{f}. \tag{2}$$

This means that total gross output produced in all country-sectors is the sum of all intermediate inputs needed for production and total final output.

Rearranging yields the fundamental input-output identity

$$\mathbf{y} = (\mathbf{I} - \mathbf{A})^{-\mathbf{1}}\mathbf{f} \tag{3}$$

where $\mathbf{I}$ is a $(SN \times SN)$ identity matrix and $(\mathbf{I} - \mathbf{A})^{-\mathbf{1}}$ is the Leontief inverse matrix.

[1] In the theoretical part, we call the units of observation sectors, whereas in the empirical part, we will observe data at the level of 30 industries and refer to aggregates of these industries as sectors.

The element in row $(i-1)S+s$ and column $(j-1)S+t$ column of this matrix represents the amount of output of sector s of country i needed to produce one unit of final output of sector t in country j.[2]

The increase of ICT capital used in production per unit of labor is called ICT capital deepening. For a growth accounting exercise identifying the contribution of ICT capital deepening to final output growth, it is essential to identify total factor requirements in production of final products along the value chain instead of factor requirements at the final stage of production. This means that intermediate input requirements are netted out. We define $\mathbf{l}$, $\mathbf{k}_N$ and $\mathbf{k}_{IT}$ as $SN \times 1$ vectors including direct labor and capital coefficients of all country-sector-units. They represent the volume of labor, non-ICT capital and capital used per unit of gross output within sectors. The total factor requirement of final output, which includes direct as well as indirect factor requirements, is then represented by $\mathbf{\Lambda}$ and $\mathbf{K}$:

$$\mathbf{\Lambda} = \hat{\mathbf{l}}(\mathbf{I} - \mathbf{A})^{-\mathbf{1}} \tag{4}$$

$$\mathbf{K_N} = \hat{\mathbf{k}}_\mathbf{N}(\mathbf{I} - \mathbf{A})^{-\mathbf{1}} \tag{5}$$

$$\mathbf{K_{IT}} = \hat{\mathbf{k}}_\mathbf{IT}(\mathbf{I} - \mathbf{A})^{-\mathbf{1}}. \tag{6}$$

The hat indicates a diagonal matrix with the elements of the vector on the diagonal. The matrices $\mathbf{\Lambda}$ and $\mathbf{K}$ have the dimension $SN \times SN$. The elements in row $(i-1)S+s$ and column $(j-1)S+t$ of such a matrix represent the requirement of factor input in sector s of country i for the production of one unit of final output in sector t of country j. They are referred to as total labor coefficients and total capital coefficients. These coefficients provide the starting point for growth accounting.

Additionally, we need output and factor prices. Factor prices are allowed to vary across sectors and countries. The prices are defined as vectors of dimension $SN \times 1$: $\mathbf{p}$ is the vector of final output prices, $\mathbf{w}$ the vector of nominal wages, $\mathbf{q}^{IT}$ the vector of nominal user costs for ICT capital and $\mathbf{q}^N$ the vector of nominal user costs for non-ICT capital. Total of factor income exhausts sectoral value added. The vector $\mathbf{v}$ contains the shares of nominal value added in nominal sectoral output. The sectoral shares of labor income in value added are then represented by the vector $\boldsymbol{\pi}^L$:

$$\hat{\boldsymbol{\pi}}^L = \hat{\mathbf{w}}\hat{\mathbf{l}}[\hat{\mathbf{p}}\hat{\mathbf{v}}]^{-\mathbf{1}}. \tag{7}$$

The sectoral compensation shares $\hat{\boldsymbol{\pi}}^N$ and $\hat{\boldsymbol{\pi}}^{IT}$ are obtained in an analogous way. The factor compensation shares of the value chain are obtained multiplying the sectoral

[2] For the theoretical exposition, this equation is expressed in volumes, which are not directly available in the data for the Leontief inverse and the vector of final use. We compute the growth rates of their elements in practice by making use of the data expressed in current prices and in previous year's prices for each year.

compensation shares by the shares of value added in total sectoral output and by the values of input required per unit of output value in the final sector:

$$\hat{\boldsymbol{\alpha}}^{\boldsymbol{L}} = \hat{\boldsymbol{\pi}}^{\boldsymbol{L}}\hat{\mathbf{v}}\hat{\mathbf{p}}^{-1}(\mathbf{I}-\mathbf{A})^{-1}\hat{\mathbf{p}} \tag{8}$$

$$\hat{\boldsymbol{\alpha}}^{\boldsymbol{N}} = \hat{\boldsymbol{\pi}}^{\boldsymbol{N}}\hat{\mathbf{v}}\hat{\mathbf{p}}^{-1}(\mathbf{I}-\mathbf{A})^{-1}\hat{\mathbf{p}} \tag{9}$$

$$\hat{\boldsymbol{\alpha}}^{\boldsymbol{IT}} = \hat{\boldsymbol{\pi}}^{\boldsymbol{IT}}\hat{\mathbf{v}}\hat{\mathbf{p}}^{-1}(\mathbf{I}-\mathbf{A})^{-1}\hat{\mathbf{p}}. \tag{10}$$

We assume that prices for specific products used as final output or as intermediates are the same.

The factor income shares and quantities derived so far can now be used for the growth accounting approach. The standard growth accounting approach at the sectoral level is modelled based on a production function of value added with direct sectoral factor inputs as arguments. In our approach, we implicitly assume a production function for final output at the value chain level with total (direct and indirect) factor input as arguments. Markets are assumed to be competitive. Following Wolff (1994) and Timmer (2017), we represent TFP growth of the value chain as a weighted sum of labor and capital cost decline. In order to distinguish it from conventional TFP at the sectoral level, TFP at the level of value chains is called effective TFP. Defining $\theta_j(t)$ as effective TFP in the production of product t in country j, we can write it as a function of labor and capital cost decline, with $\boldsymbol{\alpha}_j^L(t)'$, $\boldsymbol{\alpha}_j^N(t)'$, $\boldsymbol{\alpha}_j^{IT}(t)'$ as row vectors reflecting value shares of the costs of labor and capital from all country-sectors in the production of one unit of final output in sector t of country j, and $\boldsymbol{\Lambda}_j(t)$, $\mathbf{K}_j(t)^N$, $\mathbf{K}_j(t)^{IT}$ as $(j-1)S+t$-th columns of the factor requirement matrices:

$$-\boldsymbol{\alpha}_j^L(t)'\frac{\delta \ln \boldsymbol{\Lambda}_j(t)}{\delta \tau} = \frac{\delta \ln \theta_j(t)}{\delta \tau} + \boldsymbol{\alpha}_j^N(t)'\frac{\delta \ln \boldsymbol{K}_j^N(t)}{\delta \tau} + \boldsymbol{\alpha}_j^{IT}(t)'\frac{\delta \ln \boldsymbol{K}_j^{IT}(t)}{\delta \tau}. \tag{11}$$

The column vectors $\boldsymbol{\Lambda}_j(t)$, $\boldsymbol{K}_j^N(t)$ and $\boldsymbol{K}_j^{IT}(t)$ from $\boldsymbol{\Lambda}$, $\boldsymbol{K}^N$ and $\boldsymbol{K}^{IT}$represent total factor requirements for this value chain. Summed up over all contributing country-sectors, the elements of the cost share vectors yield the labor share and the capital share in final output of the value chain. Since all intermediate inputs are accounted for (capital and labor inputs measured being both direct and indirect), the labor and the capital share of the value chain corresponding to the sector of completion t in country j add up to unity.

We now rewrite (11) in the way that we are able to compute the contribution of ICT capital deepening to labor productivity growth. Labor productivity is defined as final output of the value chain, $f_{j,t}$, divided by the sum of the labor directly and indirectly used in its production. The column vector with the elements of labor used in the production final output is obtained multiplying the labor requirement vector $\mathbf{\Lambda}_{j,t}$ by the scalar $f_{j,t}$. The same is done for the capital requirement vectors:

$$\mathcal{L}_j(t) = f_{j,t}\mathbf{\Lambda}_j(t), \tag{12}$$

$$\mathcal{K}_j^N(t) = f_{j,t}\boldsymbol{K}_j^N(t), \tag{13}$$

$$\mathcal{K}_j^{IT}(t) = f_{j,t}\boldsymbol{K}_j^{IT}(t). \tag{14}$$

Taking the growth rates based on the previous three equations, we now isolate final output growth in equation (11) and move ICT- and non-ICT capital growth to the right-hand side. Note that final output growth and effective TFP growth in the value chain are scalars while the input growth rates are vectors. Additionally, in order to observe the influence of capital deepening instead of capital growth, we subtract the growth rates of labor input from the growth rates of capital input:

$$\begin{aligned}\frac{\delta \ln f_{j,t}}{\delta \tau} &= \frac{\delta \ln \theta_j(t)}{\delta \tau} + \alpha_j^{IT}(t)' \left(\frac{\delta \ln \mathcal{K}_j^{IT}(t)}{\delta \tau} - \frac{\delta \ln \mathcal{L}_j(t)}{\delta \tau} \right) \\ &+ \alpha_j^{N}(t)' \left(\frac{\delta \ln \mathcal{K}_j^{N}(t)}{\delta \tau} - \frac{\delta \ln \mathcal{L}_j(t)}{\delta \tau} \right) + \left(\alpha_j^{IT}(t) + \alpha_j^{N}(t) + \alpha_j^{L}(t) \right)' \frac{\delta \ln \mathcal{L}_j(t)}{\delta \tau}. \end{aligned} \tag{15}$$

To solve equation (15) for growth in labor productivity, we additionally subtract growth in labor used at all stages of the value chain on both sides:

$$\begin{aligned}\frac{\delta \ln f_{j,t}}{\delta \tau} - (\mathbf{e}'\mathcal{L}_j(t))^{-1}\mathcal{L}'_j(t)\frac{\delta \ln \mathcal{L}_j(t)}{\delta \tau} &= \frac{\delta \ln \theta_j(t)}{\delta \tau} \\ + \alpha_j^{IT}(t)' \left(\frac{\delta \ln \mathcal{K}_j^{IT}(t)}{\delta \tau} - \frac{\delta \ln \mathcal{L}_j(t)}{\delta \tau} \right) &+ \alpha_j^{N}(t)' \left(\frac{\delta \ln \mathcal{K}_j^{N}(t)}{\delta \tau} - \frac{\delta \ln \mathcal{L}_j(t)}{\delta \tau} \right) \\ + \left(\alpha_j^{IT}(t)' + \alpha_j^{N}(t)' + \alpha_j^{L}(t)' - (\mathbf{e}'\mathcal{L}_j(t))^{-1}\mathcal{L}_j(t) \right) \frac{\delta \ln \mathcal{L}_j(t)}{\delta \tau} \end{aligned} \tag{16}$$

This adds on the right-hand side a labor reallocation term that reflects the shift of labor between country-sectors with different productivity. The total of the elements of the factor share vectors adds to one, but since the sectoral labor growth rates are different, the labor growth term does not cancel. The vector $\mathbf{e}'$ represents a row vector of ones. The contribution of ICT capital-deepening to labor productivity growth is now the ICT compensation share times the growth in ICT capital per hour worked contributed directly and indirectly along the value chain.

We extend the analysis of ICT contributions to the level of final consumption instead of final production. This involves two steps, first, to isolate the part of final use that is household consumption (rather than government consumption or investment) and second, to allocate consumption products from the countries where they are finally produced to the countries where they are consumed. With this consideration, we want to see how ICT-related productivity increases benefit consumers.

In computation, we replace final output of each country-sector with final consumption expenditure of households in the country of interest in equations (12) to (14). We denote $c_{jn}(t)$ as the real final consumption expenditure produced in sector t of country j and consumed by households of country n. It is a fraction of $f_j(t)$. When $j = n$, the final products for household consumption are domestically produced, otherwise they are imported from another country. Factor inputs used directly and indirectly in the production of consumption products are then defined as:

$$\mathcal{L}_{jn}(t) = c_{jn}(t)\mathbf{\Lambda}_j(t), \tag{17}$$

$$\mathcal{K}_{jn}^{N}(t) = c_{jn}(t)\boldsymbol{K}_j^{N}(t), \tag{18}$$

$$\mathcal{K}_{jn}^{IT}(t) = c_{jn}(t)\boldsymbol{K}_j^{IT}(t). \tag{19}$$

The growth accounting equation (16) is rewritten as:

$$\begin{aligned}
&\frac{\delta \ln c_{jn}(t)}{\delta\tau} - (\mathbf{e}'\mathcal{L}_{jn}(t))^{-1}\mathcal{L}_{jn}(t)'\frac{\delta\mathcal{L}_{jn}(t)}{\delta\tau} = \frac{\delta \ln \theta_{jn}(t)}{\delta\tau} \\
&+ \alpha_j^{IT}(t)'\left(\frac{\delta \ln \mathcal{K}_{jn}^{IT}(t)}{\delta\tau} - \frac{\delta \ln \mathcal{L}_{jn}(t)}{\delta\tau}\right) + \alpha_j^{N}(t)'\left(\frac{\delta \ln \mathcal{K}_{jn}^{N}(t)}{\delta\tau} - \frac{\delta \ln \mathcal{L}_{jn}(t)}{\delta\tau}\right) \\
&+ \left(\alpha_j^{IT}(t)' + \alpha_j^{N}(t)' + \alpha_j^{L}(t)' - (\mathbf{e}'\mathcal{L}_{jn}(t))^{-1}\mathcal{L}_{jn}(t)'\right)\frac{\delta\mathcal{L}_{jn}(t)}{\delta\tau}.
\end{aligned} \tag{20}$$

Equation (20) represents the growth accounting decomposition for final consumption in country n of goods and services produced in sector t of country j. To compute the growth accounting of all final consumption of product j in country n regardless of where it is produced, we need the $N \times 1$ column vector containing the shares of nominal final consumption of this product in country n produced by each country with elements:

$$s_{jn}(t) \;=\; \frac{c_{jn}(t)}{\sum_j c_{jn}(t)}. \tag{21}$$

4 Data

The main data sources are the World-Input-Output Database (WIOD) and the EU KLEMS database. We use the 2013 release of the WIOD input-output tables and the

2012 release of the WIOD socioeconomic account data. The dataset consists of 35 ISIC rev. 3 industries for 40 countries plus a hypothetical country called Rest of World (RoW). From EU KLEMS, we use the November 2009 release of the basic files and the capital input files. The dataset consists of 32 industries for 30 countries. Capital input data are only available for a subset of countries.

The input-output tables contain data on intermediate inputs from every country-industry in the database delivered to any other country-industry as well as final use per country-industry. Tables are available in current year prices and in previous year prices. From the WIOD socio-economic accounts, we use gross output, gross output deflators, real capital stock, hours worked and capital and labor income.

In order to investigate productivity effects of ICT in growth accounting, we need data on real ICT capital stock. ICT capital stock comprises computer hardware, communications equipment and software. The lack of a separate real ICT capital stock and ICT capital income for many countries in the data represents a challenge. For 13 countries, both variables are available from the EU KLEMS 2009 release and can be easily merged (O'Mahony and Timmer, 2009). For additional four countries, at least ICT capital compensation is available.[3] For all other countries, we use information on ICT capital services and ICT capital income at the national level from the Conference Board Total Economy Database[4] to extrapolate the variables at the industry level using information from another country. Since most countries in EU KLEMS are much more ICT-intensive than the countries with missing data, we use sectoral shares of ICT capital stock and income in total capital stock and income of Italy as a country with relatively low ICT intensity as a proxy. This is an admittedly crude procedure, but in general, patterns of variation of ICT intensity across sectors are similar between countries.

Another limitation is that we are using ICT capital stock instead of ICT capital services. Capital services is a concept that takes into account different productivity of ICT assets, which may also change over time. Because of the need to aggregate capital input over the entire value chain and the limited availability of capital services data, capital stock data are used in this work as a measure of capital input.

After merging the two datasets, our dataset covers 40 countries and the Rest of the World and 30 sectors within these countries (see Appendix) for the years $1995 - 2007$ in the NACE 1.1 industry classification.

We present results for three aggregate value chains, ICT products, non-ICT goods and non-ICT services. Since the data do not allow for a separate observation of the software sector, the ICT sector in our data only includes the industries electrical and optical

[3] For Australia, Austria, Czech Republic, Denmark, Finland, Germany, Italy, Netherlands, Slovenia, Spain, Sweden, United Kingdom and United States real ICT capital stock is available from EU KLEMS. Only ICT capital compensation is available for Belgium, France, Hungary and Ireland.

[4] https://www.conference-board.org/data/economydatabase

equipment (NACE code 30t33) and post and telecommunications (64). The sector 30t33 includes the production of a small share of non-ICT goods. The countries chosen for presentation of results at the level of value chains producing final output are Australia, Finland, Germany, Italy, Spain, the United Kingdom and the United States.

5 Results

5.1 Factor and TFP Contributions to Growth along Value Chains

The results of the growth accounting analysis at the level of final products are presented in Tables A.1 to A.2 in the Appendix for two separate periods, $1995-2000$ and $2000-2007$. The 30 industries observed in the data are aggregated to three broad final sectors using the share of nominal final output of the industry in total final output of the broad sector as weights (Hulten, 1978). Since the interpretation of labor productivity growth is more complex in the case of value chains than in the case of sectors, we display final output growth and labor input growth in separate columns of Tables A.1 and A.2. Columns (3) to (6) display the elements of the growth-accounting decomposition on the right-hand side of equation (16).

Final output growth was higher for ICT products than for other products, in many cases by the factor two or three. Some countries experienced higher growth of final output in non-ICT services while others experienced higher growth in non-ICT goods. Labor productivity growth (the difference between final output growth in column (1) and labor input growth in column (2)) is higher for goods than for services. In many cases, labor input is declining in non-ICT goods production. This is reflecting the well-known process of structural change, which exists both at the level of sectors and at the level of value chains (Herrendorf et al., 2014).

Our main interest lies in the results in column (4) showing the contribution of ICT capital deepening to growth in final output and labor productivity. In the period of $1995-2000$, the highest contributions are observed in the UK and the US, where the non-ICT sectors attain contributions of $1.0-1.3$ percentage points. The contributions in other countries' non-ICT sectors range between 0.4 and 0.8 percentage points. In the period of $2000-2007$, the aggregate contribution of ICT capital deepening is declining to 0.7 percentage points in the UK and the US while being more stable other countries. The ICT sector has a higher contribution of ICT capital deepening than other sectors, but what drives the difference in labor productivity growth between sectors is TFP, not capital deepening. Whereas the contribution of non-ICT capital deepening is generally higher in goods production than in services production, the contribution of ICT capital-deepening is nearly identical for non-ICT goods and services.

The reallocation term in column (6) of Tables A.1 to A.2 reflects the move of labor input between different stages of the value chains. If labor is reallocated to sectors where labor has a higher contribution to output growth, this effect is positive. Since we do not disaggregate labor for different skill levels (which could be done in an extension of this work), measures of aggregate labor and of productivity of different labor allocations should be interpreted with caution. The labor aggregate for the value chain represents all the labor contributed by country-industries worldwide. The skill and training levels of workers may be much more heterogenous than within a single country-industry. Also the contributions by some country-industries to value chains increase from very low levels, thus exhibiting very large growth rates, for which the logarithmic approximation becomes worse (Though our sensitivity analysis, which is not reported in this paper, suggests that overall the approximation still performs reasonably well for our purposes.). As TFP growth is a residual measure, the caution in interpreting measures of labor reallocation and labor contribution to growth also has to be applied to TFP growth. Small differences in the order of 0.1 to 0.2 percentage points should not be regarded as substantial.

The growth accounting results at the level of final products show that ICT capital deepening has increased the productivity in value chains for both goods and services. While goods production is generally expected to have a higher potential for productivity growth than service production, the ICT contribution during the period observed has been nearly equal. Previous sector-level studies have already found higher ICT contributions in the US and the UK than in other countries. This result carries over to the value chain level.

5.2 Disaggregation of the ICT Contribution in Value Chains by Origin and Final Subsector

So far we have not considered how the contributions of ICT capital deepening are spread along the value chains. The question is how much do more computers or software per worker used in the final industry of production contribute, how much those used in different domestic upstream industries and how much those used in foreign upstream industries? This issue is illuminated in Tables A.3 to A.16, which decompose column (4) of A.1 and A.2 by origin. Moreover, the tables split down the final sectors further, which reveals differences within goods production and within services.

The breakdown by sectoral origin is obtained by splitting the vector $\alpha_j^{IT}(t)$ in equation (16) into different parts with the irrelevant elements being set to zero.

We use a breakdown of six subsectors, which implies that upstream linkages of an industry to other subsectors are visible whereas upstream linkages within the same subsector cannot be distinguished from the final stage of the value chain. Rows indicate categories of goods and services which are finally produced in a particular country.

Columns (1) to (7) indicate contributions along a value chain by different domestic sectors. Column (8) represents the aggregate foreign contribution and column (9) the total contribution. The elements on the diagonal represent contributions of capital deepening taking place within the sector of completion of the value chain.

Foreign ICT capital deepening is contributing relatively little to productivity growth in value chains. The highest contribution amounting to 0.25 percentage points is observed in Finnish ICT production between 1995 and 2000. Most values outside the ICT sector lie below 0.1 percentage points. Domestic upstream contributions are generally more important. For the production of non-ICT manufactured and other goods, more than half of the ICT capital deepening takes place in domestic or foreign upstream industries outside the final sectors. For some countries and periods, this is also the case for other services and for the ICT sector. Only for distribution and financial services, more than half of capital deepening is consistently contributed within the final sector. The foreign contribution, while remaining overall low, is also higher for goods production than for services. This reflects a higher degree of fragmentation and offshoring. Germany is an example for a country where the contribution of ICT capital deepening in upstream sectors is particularly high. The contributions in value chains of non-ICT manufacturing and other goods production during the period $1995-2000$ amount to 0.45 and 0.34 percentage points, of which only 0.1 and 0.04 are contributed in the final sector.

Moreover, the breakdown by final subsectors reveals differences in the contribution of ICT capital deepening within goods production and within services. Value chains of manufactured goods display consistently higher contributions than the value chains classified as other goods in the same countries. The same is true when comparing distribution services and business and financial services to other services.

Turning to the sectoral origin of ICT contributions, we observe that the most important domestic upstream sector contributing to productivity growth through ICT capital deepening is the sector of financial and business services. It is followed by the sector of distribution services. The other sectors transfer only small ICT-related contributions downstream, which in most cases lie below an annual 0.05 percentage points. In the US, the downstream contributions of ICT capital deepening in financial and business services to the five other sectors lie between 0.33 and 0.45 percentage points per year in the period $1995-2000$. Those by distribution services lie between 0.04 and 0.19. In the period $2000-2007$, the contributions are lower, but still amount to 0.19 to 0.25 percentage points for financial and business services. The UK also displays contributions by financial and business services to each of the five other sectors between 0.29 and 0.58 percentage points. The contributions of distribution services are somewhat lower than in the US. Australia is the country with the third highest contributions.

5.3 ICT Contribution to Final Consumption Growth

Productivity growth is a key goal of economic policy since it increases incomes, lowers prices and increases the quality of products for consumers. Our perspective using the value chain approach is not the income but the consumption side. So far we have observed products at their country-industry of completion and not yet at their destination of final use. By definition, there are four final uses of products: private consumption, government consumption, investment and export. At the world-wide level, all export is finally used in one of the three other categories.

We take a closer look at private consumption only, ignoring government consumption and investment for several reasons: Investment unfolds its effect on living standard only once it is used in production. Integrating this effect into the growth accounting setting could be possible using the approach proposed by Aulin-Ahmavaara (1999), but this exceeds the scope of the present paper. Government consumption in turn involves products such as general administrative services, education and health services, for which productivity growth is particularly hard to measure. Moreover, private consumption reflects most directly the products people freely choose to consume. Formally, the analysis could be conducted for government consumption in an analogous way.

Growth accounting results for final consumption displayed in Tables A.17 and A.18 represent weighted averages of the results for the country-industries of completion of the product. Comparing the results at the value chain level from Tables A.1 and A.2 to the results at the level of private consumption, the differences in the contribution of ICT capital deepening to productivity growth turn out to be small for the strongly aggregated products categories we consider. In total, consumers in a country experience roughly the same effects of ICT capital deepening as the final users of the countries' products. Output growth is different between these two categories, which is not surprising because consumption may easily grow at a different rate than total final production.

In the interpretation of the results, we have to pay attention to the fact that the final use data available from the WIOT are at basic prices, which means they exclude trade and transport margins. The part of the consumption value of goods and services contributed by the trade and transport industries is thus counted as part of these industries' final output.

To address now the question whether digitalization benefitted consumers more via ICT products or via indirect effects on other products, consider the following back-of-the-envelope calculation: Assume household consumption of ICT is five percent of total household consumption and the productivity increase from TFP and ICT capital deepening in ICT production is five percent per year (Since we do not observe the ICT sector in an exact way, using the TFP growth rates and shares corresponding to our proxy of the sector would not be more precise here. The TFP growth is likely to be underestimated in our results since it includes non-ICT electrical and optical products.). Then the productivity benefit digitalization has for consumers in the form of better and cheaper ICT products would be 0.25 percentage points per year. This is below the contribution of ICT capital deepening found in value chains of other products, which ranges roughly between 0.5 and 1.0 percentage points. The latter is not decreased a lot when multiplied by a budget share of 95 percent. But the benefits from ICT products appear more spectacular since they represent strong improvements concentrated on a small share of the overall consumption budget. For non-ICT products, benefits from digitalization reach the consumer in the form of much slower and broad-based improvements and cost reductions. But their overall impact on living standards is likely to be more important than for ICT products during the period we observe.

In Table A.19, we break down ICT capital deepening by country origin. We add an indicator of the weighted relative domestic contribution to check whether domestic or foreign sectors add more or to productivity growth in the provision of final consumption when the contributions are divided by the shares of domestic consumption products and imported ones. More precisely, the indicator divides the ratio of the added domestic and foreign ICT capital deepening contributions by the ratio of the shares of domestic and foreign consumption products. During 1995−2000, the relative domestic ICT contribution exceeds one only in the UK and the US. In the subsequent period, Australia also shows this pattern for goods production while it vanishes for British ICT goods production. The magnitudes of these differences remain moderate in what they mean for overall productivity growth.

5.4 Contribution of TFP Growth in the ICT Sector to Value Chains

In addition to ICT capital deepening along the value chain, ICT products are used as intermediate products, which may also increase the overall labor productivity in value chains. Growth accounting at the level of value chains replaces all intermediate products by the capital, the labor and the TFP contributing to their production. In this way, it is also possible to identify the contribution of TFP growth originating in the ICT-producing sector to final output growth in all value chains. This is done setting all cost shares from contributing non-ICT sectors in equation (16) to zero in order to isolate the TFP growth originating in the ICT sector. The results are shown in Table A.21.

The ICT sector itself has very high rates of conventional (i.e. sector-level) TFP growth and it can be expected that part of it is passed on downstream via the use of intermediate ICT goods and services. Yet, these downstream effects turn out to be low. While some countries exhibit average annual effective TFP growth rates for ICT products as high as 4 percent, the contributions to other value chains lie below 0.2 percentage points, in most cases even below 0.1 percentage points. They are generally lower than the contributions from ICT capital deepening, which attain values of around 0.5 percentage points (see previous paragraphs on Tables A.1 and A.2). Since total effective rates of TFP growth in non-ICT goods and services production are between slightly negative and 3 percentage points, the TFP contribution from the ICT sector is also moderate in relative terms.

6 Conclusion

This paper investigates ICT-related productivity increases along value chains of goods finally produced and consumed in different countries. Orders of magnitude and country differences in the contribution of ICT capital deepening along value chains are in line with those found in previous sector-level studies. The aggregate contribution is similar for value chains of non-ICT goods and non-ICT services. Looking deeper at the origin of the contributions, we find that foreign capital deepening contributes relatively little to productivity growth along value chains. While the phenomena of digitalization and globalization may be related in various ways, we find little evidence of ICT-related productivity growth being imported via intermediate inputs. It still may be the case that ICT investments enable new offshoring relations, but the ICT investments in the exporting countries themselves contribute little to productivity growth along value chains. Our imputation of missing values for ICT capital may underestimate some foreign contributions, but we do not expect this effect to be very large.

Domestic upstream contributions of ICT capital deepening to productivity growth play a more important role. For goods production, far more than half of the ICT contribution originates in upstream sectors. Policies aiming at digitalization of a sector with the goal of improving the competitivity of the goods produced should take into account that the final stage of production may have a limited potential for this. Since most of the contributions along the value chains are domestic, fostering digitalization of national value chains could have a far greater effect.

The most important upstream sector contributing to productivity growth in value chains is the sector of business and financial services, followed by distribution services. Growth accounting along value chains thus suggests that the spread of ICT increased particularly the productivity of the service contributions to value chains and did so through services that use information and knowledge intensively. As far as we can see at a relatively high level of aggregation, this contribution does not concentrate on particular sets of products but is spread throughout the economy, indicating that ICT is a general purpose technology. The contribution via ICT capital goods is much stronger than the contribution via ICT intermediates. On the consumption side, the results on the magnitude of productivity increase through ICT capital deepening are similar. The UK and the US, which experienced strong ICT-related growth during $1995-2000$ consume on average products that incorporate less ICT-related productivity growth than the products they produce. The converse is true for most other countries.

After the financial crisis of 2008, the strong measured contribution of business and financial services has to be interpreted with caution. It is possible that part of the effect does not correctly measure the productivity contribution of this sector.

This is to our knowledge the first paper to analyze ICT-related productivity gains in a growth accounting framework of value chains. It has set out the methodology and generated results at level of aggregated sectors of final goods. Further work could integrate capital as a produced input. When we currently split the contribution of ICT capital deepening into a domestic and a foreign contribution, we consider in which country the ICT capital was used to produce value added, but not in which country the capital itself was produced. This could be done following the approach by Aulin-Ahmavaara (1999). Also further possible applications of growth accounting along value chains are not limited to ICT-related productivity contributions. The contribution of labor growth to output growth could be investigated further decomposing labor by skill levels.

A Appendix

A.1 Growth Accounting Results

Table A.1: Decomposition of Final Output Growth in Value Chains 1995 - 2000
Percent

	(1) Growth of final output	(2) Growth of labor input	(3) Growth of TFP	(4) Contrib. ICT/labor	(5) Contrib. non-ICT/labor	(6) Contrib. realloc.
Australia						
ICT products	8.7	4.5	1.4	1.3	0.5	1.0
Non-ICT goods	2.8	-0.9	1.7	0.7	0.6	0.7
Non-ICT services	3.3	0.3	1.4	0.8	0.1	0.8
Total	3.4	0.2	1.5	0.8	0.2	0.8
Finland						
ICT products	17.1	7.2	8.1	1.0	1.0	-0.1
Non-ICT goods	2.4	-2.6	2.7	0.5	0.3	1.5
Non-ICT services	3.7	0.9	1.4	0.6	0.1	0.8
Total	4.5	0.7	2.1	0.6	0.2	0.9
Germany						
ICT products	6.2	1.1	4.2	0.5	0.4	0.0
Non-ICT goods	2.8	0.2	1.9	0.5	0.5	-0.3
Non-ICT services	1.3	-1.1	0.6	0.4	0.3	1.1
Total	2.0	-0.7	1.1	0.4	0.4	0.7
Italy						
ICT products	4.7	2.1	1.6	0.5	0.3	0.2
Non-ICT goods	2.5	-0.5	1.0	0.4	0.6	0.9
Non-ICT services	1.6	0.7	0.2	0.4	0.1	0.2
Total	1.9	0.4	0.5	0.4	0.3	0.4
Spain						
ICT products	9.0	6.5	0.7	1.2	0.8	-0.2
Non-ICT goods	5.2	2.3	1.2	0.4	0.6	0.8
Non-ICT services	4.1	3.8	-0.5	0.3	-0.4	0.8
Total	4.5	3.5	0.0	0.4	-0.1	0.7
UK						
ICT products	10.6	2.6	5.0	1.6	1.0	0.4
Non-ICT goods	1.6	-2.2	0.7	1.0	1.0	1.0
Non-ICT services	3.8	1.2	0.1	1.3	0.8	0.4
Total	3.7	0.6	0.5	1.2	0.9	0.5
US						
ICT products	12.1	5.1	4.3	2.1	0.7	-0.2
Non-ICT goods	3.5	-0.1	1.1	1.2	0.6	0.7
Non-ICT services	4.3	2.5	0.3	1.1	0.6	-0.2
Total	4.5	2.2	0.6	1.2	0.6	-0.1

Table A.2: Decomposition of Final Output Growth in Value Chains 2000 - 2007
Percent

	(1) Growth of final output	(2) Growth of labor input	(3) Growth of TFP	(4) Contrib. ICT/labor	(5) Contrib. non-ICT/labor	(6) Contrib. realloc.
Australia						
ICT products	6.2	3.5	0.9	1.3	0.5	0.0
Non-ICT goods	0.9	-0.9	-0.3	0.9	1.0	0.2
Non-ICT services	4.3	2.8	0.1	1.0	0.1	0.4
Total	3.9	2.3	0.0	1.0	0.2	0.3
Finland						
ICT products	6.2	-3.0	5.7	0.8	0.7	2.1
Non-ICT goods	2.3	-3.3	2.8	0.4	0.5	1.8
Non-ICT services	2.5	-0.1	0.3	0.5	0.3	1.4
Total	2.8	-0.9	1.2	0.5	0.4	1.5
Germany						
ICT products	4.8	1.0	3.2	0.5	0.3	-0.3
Non-ICT goods	1.3	-1.1	1.8	0.4	0.5	-0.2
Non-ICT services	0.4	-1.7	0.5	0.3	0.4	0.8
Total	0.9	-1.4	1.0	0.3	0.4	0.5
Italy						
ICT products	2.6	0.5	0.7	0.3	0.7	0.5
Non-ICT goods	0.2	-1.7	0.1	0.2	0.4	1.1
Non-ICT services	1.5	0.1	-0.1	0.2	0.1	1.2
Total	1.2	-0.4	0.0	0.2	0.2	1.2
Spain						
ICT products	4.7	2.1	1.2	0.5	0.6	0.3
Non-ICT goods	1.2	-2.1	0.8	0.3	0.7	1.4
Non-ICT services	4.2	2.7	-0.1	0.3	0.2	1.0
Total	3.6	1.7	0.2	0.3	0.3	1.1
UK						
ICT products	-2.6	-5.7	2.4	0.8	0.6	-0.7
Non-ICT goods	-0.5	-4.3	2.6	0.6	0.8	-0.3
Non-ICT services	3.7	1.5	0.3	0.8	0.7	0.4
Total	2.8	0.4	0.7	0.7	0.7	0.2
US						
ICT products	3.5	-2.7	4.5	1.0	0.6	0.2
Non-ICT goods	1.0	-3.4	2.8	0.8	0.5	0.4
Non-ICT services	2.6	0.5	0.6	0.7	0.4	0.3
Total	2.4	-0.1	1.0	0.7	0.4	0.3

Table A.3: Decomposition of ICT Capital Deepening by Final Sector and Sector of Origin (Australia), 1995-2000
Percent

Final sector \ Sector of origin	(1) ICT sector	(2) Non-ICT manufacturing	(3) Other goods production	(4) Distribution services	(5) Finance and business services	(6) Other services	(7) Domestic Aggr.	(8) Foreign Aggr.	(9) Total
ICT	0.90	0.04	0.03	0.08	0.08	0.01	1.14	0.12	1.26
Non-ICT manufactured goods	0.03	0.36	0.05	0.10	0.09	0.01	0.66	0.12	0.78
Other goods	0.03	0.09	0.23	0.08	0.14	0.01	0.58	0.10	0.69
Distribution services	0.06	0.04	0.03	0.45	0.13	0.02	0.73	0.09	0.82
Finance and business services	0.03	0.02	0.02	0.03	0.63	0.01	0.74	0.04	0.78
Other services	0.05	0.04	0.02	0.04	0.10	0.48	0.73	0.07	0.80

Table A.4: Decomposition of ICT Capital Deepening by Final Sector and Sector of Origin (Australia), 2000-2007
Percent

Final sector \ Sector of origin	(1) ICT sector	(2) Non-ICT manufacturing	(3) Other goods production	(4) Distribution services	(5) Finance and business services	(6) Other services	(7) Domestic Aggr.	(8) Foreign Aggr.	(9) Total
ICT	0.85	0.05	0.04	0.12	0.14	0.01	1.20	0.06	1.26
Non-ICT manufactured goods	0.03	0.51	0.08	0.18	0.17	0.01	0.98	0.07	1.05
Other goods	0.03	0.09	0.37	0.11	0.24	0.01	0.84	0.05	0.89
Distribution services	0.04	0.05	0.04	0.77	0.20	0.01	1.12	0.05	1.16
Finance and business services	0.02	0.02	0.02	0.04	0.93	0.01	1.05	0.02	1.07
Other services	0.03	0.05	0.03	0.07	0.15	0.42	0.75	0.04	0.79

Table A.5: Decomposition of ICT Capital Deepening by Final Sector and Sector of Origin (Finland), 1995-2000
Percent

Final sector \ Sector of origin	(1) ICT sector	(2) Non-ICT manufacturing	(3) Other goods production	(4) Distribution services	(5) Finance and business services	(6) Other services	(7) Domestic Aggr.	(8) Foreign Aggr.	(9) Total
ICT	0.60	0.02	0.01	0.05	0.09	0.01	0.78	0.25	1.03
Non-ICT manufactured goods	0.03	0.19	0.01	0.07	0.07	0.01	0.39	0.17	0.55
Other goods	0.02	0.04	0.22	0.07	0.07	0.00	0.43	0.13	0.56
Distribution services	0.04	0.02	0.01	0.43	0.07	0.00	0.58	0.11	0.69
Finance and business services	0.02	0.02	0.04	0.03	0.58	0.01	0.69	0.07	0.76
Other services	0.03	0.02	0.01	0.03	0.08	0.23	0.41	0.09	0.49

Table A.6: Decomposition of ICT Capital Deepening by Final Sector and Sector of Origin (Finland), 2000-2007
Percent

Final sector \ Sector of origin	(1) ICT sector	(2) Non-ICT manufacturing	(3) Other goods production	(4) Distribution services	(5) Finance and business services	(6) Other services	(7) Domestic Aggr.	(8) Foreign Aggr.	(9) Total
ICT	0.47	0.01	0.01	0.02	0.09	0.01	0.62	0.16	0.78
Non-ICT manufactured goods	0.02	0.16	0.01	0.04	0.08	0.00	0.31	0.13	0.44
Other goods	0.02	0.03	0.17	0.04	0.07	0.00	0.33	0.09	0.42
Distribution services	0.02	0.03	0.01	0.24	0.08	0.01	0.38	0.08	0.46
Finance and business services	0.02	0.01	0.02	0.01	0.75	0.01	0.82	0.05	0.87
Other services	0.02	0.01	0.01	0.02	0.07	0.22	0.35	0.05	0.41

Table A.7: Decomposition of ICT Capital Deepening by Final Sector and Sector of Origin (Germany), 1995-2000
Percent

Final sector \ Sector of origin	(1) ICT sector	(2) Non-ICT manufacturing	(3) Other goods production	(4) Distribution services	(5) Finance and business services	(6) Other services	(7) Domestic Aggr.	(8) Foreign Aggr.	(9) Total
ICT	0.10	0.01	0.00	0.03	0.17	0.00	0.31	0.15	0.46
Non-ICT manufactured goods	0.00	0.10	0.00	0.04	0.17	0.00	0.32	0.14	0.45
Other goods	0.00	0.02	0.04	0.03	0.15	0.00	0.25	0.09	0.34
Distribution services	0.00	0.01	0.00	0.32	0.16	0.00	0.49	0.06	0.55
Finance and business services	0.00	0.00	0.00	0.01	0.51	0.00	0.53	0.05	0.57
Other services	0.00	0.01	0.00	0.02	0.11	0.12	0.26	0.05	0.31

Table A.8: Decomposition of ICT Capital Deepening by Final Sector and Sector of Origin (Germany), 2000-2007
Percent

Final sector \ Sector of origin	(1) ICT sector	(2) Non-ICT manufacturing	(3) Other goods production	(4) Distribution services	(5) Finance and business services	(6) Other services	(7) Domestic Aggr.	(8) Foreign Aggr.	(9) Total
ICT	0.23	0.01	0.00	0.03	0.11	0.00	0.38	0.10	0.48
Non-ICT manufactured goods	0.01	0.10	0.00	0.04	0.11	0.00	0.27	0.10	0.37
Other goods	0.01	0.01	0.04	0.02	0.10	0.00	0.19	0.06	0.25
Distribution services	0.01	0.01	0.00	0.27	0.09	0.00	0.39	0.04	0.43
Finance and business services	0.00	0.00	0.00	0.00	0.33	0.00	0.35	0.04	0.38
Other services	0.01	0.01	0.00	0.01	0.07	0.14	0.23	0.03	0.27

Table A.9: Decomposition of ICT Capital Deepening by Final Sector and Sector of Origin (Italy), 1995-2000
Percent

Sector of origin / Final sector	(1) ICT sector	(2) Non-ICT manufacturing	(3) Other goods production	(4) Distribution services	(5) Finance and business services	(6) Other services	(7) Domestic Aggr.	(8) Foreign Aggr.	(9) Total
ICT	0.27	0.02	0.01	0.04	0.05	0.01	0.40	0.14	0.54
Non-ICT manufactured goods	0.01	0.14	0.01	0.06	0.05	0.01	0.28	0.12	0.40
Other goods	0.01	0.03	0.09	0.04	0.05	0.01	0.22	0.08	0.30
Distribution Services	0.01	0.02	0.01	0.28	0.07	0.01	0.39	0.08	0.47
Finance and business services	0.00	0.00	0.00	0.01	0.32	0.00	0.35	0.03	0.38
Other services	0.01	0.01	0.00	0.02	0.03	0.20	0.27	0.04	0.32

Table A.10: Decomposition of ICT Capital Deepening by Final Sector and Sector of Origin (Italy), 2000-2007
Percent

Sector of origin / Final sector	(1) ICT sector	(2) Non-ICT manufacturing	(3) Other goods production	(4) Distribution services	(5) Finance and business services	(6) Other services	(7) Domestic Aggr.	(8) Foreign Aggr.	(9) Total
ICT	0.14	0.01	0.00	0.02	0.03	0.00	0.21	0.08	0.29
Non-ICT manufactured goods	0.01	0.08	0.00	0.03	0.03	0.00	0.15	0.09	0.24
Other goods	0.01	0.01	0.05	0.02	0.03	0.00	0.12	0.05	0.17
Distribution services	0.01	0.01	0.00	0.10	0.04	0.00	0.17	0.06	0.23
Finance and business services	0.00	0.00	0.00	0.00	0.17	0.00	0.19	0.02	0.20
Other services	0.00	0.01	0.00	0.01	0.02	0.17	0.21	0.03	0.24

Table A.11: Decomposition of ICT Capital Deepening by Final Sector and Sector of Origin (Spain), 1995-2000
Percent

Final sector \ Sector of origin	(1) ICT sector	(2) Non-ICT manufacturing	(3) Other goods production	(4) Distribution services	(5) Finance and business services	(6) Other services	(7) Domestic Aggr.	(8) Foreign Aggr.	(9) Total
ICT	0.93	0.01	0.00	0.05	0.06	0.00	1.06	0.13	1.19
Non-ICT manufactured goods	0.03	0.10	0.01	0.09	0.05	0.00	0.28	0.14	0.42
Other goods	0.03	0.02	0.04	0.06	0.06	0.00	0.21	0.08	0.29
Distribution services	0.03	0.01	0.00	0.45	0.06	0.00	0.55	0.07	0.62
Finance and business services	0.04	0.01	0.01	0.02	0.25	0.00	0.33	0.04	0.36
Other services	0.03	0.01	0.00	0.03	0.04	0.09	0.21	0.05	0.26

Table A.12: Decomposition of ICT Capital Deepening by Final Sector and Sector of Origin (Spain), 2000-2007
Percent

Final sector \ Sector of origin	(1) ICT sector	(2) Non-ICT manufacturing	(3) Other goods production	(4) Distribution services	(5) Finance and business services	(6) Other services	(7) Domestic Aggr.	(8) Foreign Aggr.	(9) Total
ICT	0.30	0.02	0.01	0.03	0.04	0.01	0.40	0.10	0.50
Non-ICT manufactured goods	0.01	0.12	0.01	0.06	0.04	0.01	0.24	0.11	0.35
Other goods	0.01	0.03	0.09	0.03	0.04	0.01	0.20	0.06	0.25
Distribution services	0.01	0.01	0.01	0.27	0.05	0.01	0.35	0.05	0.40
Finance and business services	0.01	0.01	0.01	0.01	0.31	0.01	0.37	0.04	0.40
Other services	0.01	0.01	0.00	0.02	0.03	0.22	0.29	0.04	0.33

Table A.13: Decomposition of ICT Capital Deepening by Final Sector and Sector of Origin (UK), 1995-2000
Percent

Final sector \ Sector of origin	(1) ICT sector	(2) Non-ICT manufacturing	(3) Other goods production	(4) Distribution services	(5) Finance and business services	(6) Other services	(7) Domestic Aggr.	(8) Foreign Aggr.	(9) Total
ICT	0.76	0.03	0.01	0.11	0.44	0.01	1.36	0.19	1.56
Non-ICT manufactured goods	0.03	0.31	0.02	0.12	0.43	0.01	0.92	0.13	1.06
Other goods	0.03	0.04	0.26	0.07	0.49	0.01	0.90	0.08	0.98
Distribution services	0.04	0.03	0.01	0.73	0.58	0.01	1.40	0.07	1.47
Finance and business services	0.06	0.02	0.02	0.03	1.78	0.01	1.92	0.06	1.97
Other services	0.03	0.03	0.01	0.06	0.47	0.23	0.84	0.08	0.92

Table A.14: Decomposition of ICT Capital Deepening by Final Sector and Sector of Origin (UK), 2000-2007
Percent

Final sector \ Sector of origin	(1) ICT sector	(2) Non-ICT manufacturing	(3) Other goods production	(4) Distribution services	(5) Finance and business services	(6) Other services	(7) Domestic Aggr.	(8) Foreign Aggr.	(9) Total
ICT	0.29	0.02	0.01	0.06	0.29	0.01	0.66	0.11	0.77
Non-ICT manufactured goods	0.01	0.22	0.01	0.08	0.29	0.01	0.61	0.09	0.70
Other goods	0.01	0.02	0.15	0.04	0.30	0.01	0.52	0.05	0.57
Distribution services	0.01	0.01	0.01	0.41	0.38	0.01	0.82	0.04	0.87
Finance and business services	0.02	0.01	0.01	0.01	1.12	0.01	1.18	0.04	1.21
Other services	0.01	0.01	0.01	0.04	0.31	0.10	0.48	0.05	0.53

Table A.15: Decomposition of ICT Capital Deepening by Final Sector and Sector of Origin (US), 1995-2000
Percent

Sector of origin / Final sector	(1) ICT sector	(2) Non-ICT manufacturing	(3) Other goods production	(4) Distribution services	(5) Finance and business services	(6) Other services	(7) Domestic Aggr.	(8) Foreign Aggr.	(9) Total
ICT	1.31	0.06	0.01	0.14	0.45	0.01	1.98	0.09	2.07
Non-ICT manufactured goods	0.07	0.48	0.03	0.19	0.39	0.01	1.17	0.08	1.24
Other goods	0.06	0.08	0.33	0.15	0.37	0.01	1.00	0.05	1.05
Distribution services	0.07	0.03	0.01	0.91	0.33	0.01	1.35	0.03	1.38
Finance and business services	0.04	0.02	0.01	0.04	1.33	0.01	1.44	0.02	1.46
Other Services	0.07	0.05	0.02	0.09	0.34	0.24	0.81	0.03	0.84

Table A.16: Decomposition of ICT Capital Deepening by Final Sector and Sector of Origin (US), 2000-2007
Percent

Sector of origin / Final sector	(1) ICT sector	(2) Non-ICT manufacturing	(3) Other goods production	(4) Distribution services	(5) Finance and business services	(6) Other services	(7) Domestic Aggr.	(8) Foreign Aggr.	(9) Total
ICT	0.60	0.03	0.01	0.08	0.25	0.01	0.97	0.05	1.02
Non-ICT manufactured goods	0.03	0.35	0.02	0.12	0.24	0.01	0.77	0.05	0.82
Other goods	0.02	0.05	0.21	0.09	0.20	0.01	0.58	0.03	0.61
Distribution services	0.02	0.02	0.01	0.61	0.19	0.00	0.86	0.02	0.88
Finance and business services	0.02	0.01	0.01	0.02	0.79	0.01	0.85	0.01	0.86
Other services	0.03	0.03	0.01	0.05	0.23	0.17	0.52	0.02	0.54

Table A.17: Decomposition of Final Consumption Growth based on Value Chains 1995 - 2000
Percent

	(1) Growth of fin. consumption	(2) Growth of labor input	(3) Growth of TFP	(4) Contrib. ICT/labor	(5) Contrib. non-ICT/labor	(6) Contrib. realloc.
Australia						
ICT products	8.6	3.6	2.4	1.3	0.6	0.6
Non-ICT goods	1.7	-2.4	1.8	0.8	0.7	0.9
Non-ICT services	3.9	0.4	1.5	0.8	0.0	1.2
Total	3.5	-0.3	1.6	0.8	0.3	1.1
Finland						
ICT products	18.0	8.7	6.4	1.2	0.8	0.9
Non-ICT goods	1.9	-3.7	2.6	0.6	0.6	1.8
Non-ICT services	3.0	-0.2	1.6	0.6	0.1	0.8
Total	3,3	-0.7	2.1	0.6	0.3	1.1
Germany						
ICT products	6.1	0.5	4.0	0.5	0.4	0.8
Non-ICT goods	0.5	-3.3	2.1	0.5	0.6	0.5
Non-ICT services	1.3	-2.2	0.6	0.4	0.2	2.3
Total	1.2	-2.5	1.3	0.5	0.4	1.6
Italy						
ICT products	9.4	5.3	2.6	0.6	0.2	0.7
Non-ICT goods	2.4	-1.4	1.2	0.4	0.7	1.5
Non-ICT services	1.7	0.5	0.4	0.4	0.0	0.3
Total	2.2	0.0	0.8	0.4	0.3	0.7
Spain						
ICT products	11.8	7.8	1.4	1.4	1.1	0.1
Non-ICT goods	3.8	0.3	1.3	0.5	0.6	1.1
Non-ICT services	3.3	2.7	-0.6	0.4	-0.7	1.5
Total	3.7	1.9	0.2	0.4	-0.1	1.3
UK						
ICT products	11.8	2.2	6.2	1.9	0.8	0.7
Non-ICT goods	3.9	-0.3	1.1	1.0	1.0	1.1
Non-ICT services	4.2	1.4	0.0	1.6	0.9	0.4
Total	4.5	0.9	0.6	1.4	0.9	0.6
US						
ICT products	9.1	4.4	1.8	2.3	0.5	0.2
Non-ICT goods	4.7	0.4	1.4	1.1	0.6	1.3
Non-ICT services	4.3	2.2	0.6	1.1	0.6	-0.3
Total	4.5	2.0	0.8	1.2	0.6	0.0

Table A.18: Decomposition of Final Consumption Growth based on Value Chains 2000 - 2007
Percent

	(1) Growth of fin. consumption	(2) Growth of labor input	(3) Growth of TFP	(4) Contrib. ICT/labor	(5) Contrib. non-ICT/labor	(6) Contrib. realloc.
Australia						
ICT products	8.1	4.6	1.7	1.2	0.5	0.1
Non-ICT goods	3.7	1.4	0.6	0.8	0.8	0.2
Non-ICT services	3.5	2.0	-0.1	1.0	0.1	0.5
Total	3.7	1.9	0.1	1.0	0.3	0.4
Finland						
ICT products	9.4	1.9	4.2	0.7	0.6	1.9
Non-ICT goods	5.0	-0.1	2.6	0.4	0.7	1.5
Non-ICT services	3.1	-0.4	0.4	0.7	0.4	2.0
Total	3.9	-0.3	1.3	0.6	0.5	1.8
Germany						
ICT products	4.1	0.0	2.7	0.6	0.3	0.5
Non-ICT goods	-0.8	-4.2	1.7	0.4	0.6	0.7
Non-ICT services	1.0	-1.7	0.6	0.3	0.6	1.1
Total	0.6	-2.4	1.1	0.4	0.6	1.0
Italy						
ICT products	4.0	0.8	1.6	0.3	0.8	0.4
Non-ICT goods	0.2	-2.4	0.6	0.3	0.5	1.3
Non-ICT services	1.1	-0.7	-0.1	0.2	-0.2	1.8
Total	0.9	-1.1	0.2	0.2	0.1	1.6
Spain						
ICT products	8.0	4.6	1.7	0.6	0.6	0.5
Non-ICT goods	3.4	-0.4	1.2	0.4	0.7	1.6
Non-ICT services	3.3	1.5	-0.2	0.4	0.1	1.5
Total	3.5	1.1	0.3	0.4	0.3	1.5
UK						
ICT products	3.5	-0.4	2.8	0.7	0.6	-0.2
Non-ICT goods	2.0	-1.9	2.3	0.5	0.7	0.4
Non-ICT services	3.9	1.3	0.6	0.7	0.8	0.4
Total	3.4	0.4	1.1	0.7	0.8	0.4
US						
ICT products	5.4	0.3	3.4	1.1	0.5	0.1
Non-ICT goods	1.8	-2.1	2.3	0.7	0.5	0.4
Non-ICT services	3.1	0.5	0.9	0.7	0.5	0.5
Total	2.9	0.1	1.2	0.7	0.5	0.4

Table A.19: Decomposition of Contribution of ICT Capital Deepening to Final Consumption Growth, 1995-2000
Percent, column 4 indicator with reference value 1

Sector	(1) Total	(2) Domestic	(3) Foreign	(4) Relative domestic
Australia				
ICT goods	1.0	0.2	0.8	0.52
Non-ICT manufactured goods	0.8	0.6	0.2	0.69
Other goods	0.5	0.4	0.0	0.19
Finland				
ICT goods	1.0	0.4	0.6	0.57
Non-ICT manufactured goods	0.6	0.4	0.2	0.44
Other goods	0.3	0.2	0.0	0.31
Germany				
ICT goods	0.8	0.4	0.4	0.28
Non-ICT manufactured goods	0.5	0.3	0.2	0.31
Other goods	0.2	0.1	0.2	0.1
Italy				
ICT goods	0.7	0.4	0.4	0.24
Non-ICT manufactured goods	0.4	0.3	0.1	0.19
Other goods	0.2	0.1	0.1	0.48
Spain				
ICT goods	0.8	0.3	0.5	0.48
Non-ICT manufactured goods	0.5	0.3	0.2	0.28
Other goods	0.2	0.2	0.1	0.19
UK				
ICT goods	1.2	0.5	0.7	1.13
Non-ICT manufactured goods	1.0	0.8	0.2	1.27
Other goods	0.7	0.6	0.1	1.45
US				
ICT goods	1.3	1.0	0.3	2.12
Non-ICT manufactured goods	1.1	0.9	0.1	1.38
Other goods	0.7	0.7	0.0	1.45

Table A.20: Decomposition of Contribution of ICT Capital Deepening to Final Consumption Growth, 2000-2007
Percent

	(1) Total	(2) Domestic	(3) Foreign	(4) Relative domestic
Australia				
ICT goods	0.7	0.2	0.5	1.24
Non-ICT manufactured goods	0.8	0.7	0.2	1.61
Other goods	0.6	0.6	0.0	0.65
Finland				
ICT goods	0.7	0.3	0.4	0.90
Non-ICT manufactured goods	0.4	0.2	0.2	0.56
Other goods	0.2	0.2	0.0	0.38
Germany				
ICT goods	0.5	0.1	0.4	0.43
Non-ICT manufactured goods	0.4	0.2	0.2	0.49
Other goods	0.2	0.1	0.1	0.50
Italy				
ICT goods	0.4	0.2	0.2	0.28
Non-ICT manufactured goods	0.3	0.2	0.1	0.22
Other goods	0.1	0.1	0.0	0.17
Spain				
ICT goods	0.5	0.1	0.4	0.16
Non-ICT manufactured goods	0.4	0.2	0.1	0.42
Other goods	0.2	0.1	0.0	0.26
UK				
ICT goods	0.6	0.2	0.4	0.85
Non-ICT manufactured goods	0.5	0.3	0.2	1.07
Other goods	0.3	0.3	0.1	1.21
US				
ICT goods	0.7	0.5	0.2	1.39
Non-ICT manufactured goods	0.7	0.5	0.1	1.45
Other goods	0.4	0.4	0.0	1.84

Table A.21: TFP Growth Contributed by ICT Sector to Different Final Products
Percent

	(1) 1995-2000	(2) 2000-2007
Australia		
ICT products	0.41	0.57
Non-ICT goods	0.03	0.02
Non-ICT services	0.08	0.02
Total	0.08	0.03
Finland		
ICT sector	4.61	2.94
Non-ICT goods	0.15	0.13
Non-ICT services	0.10	0.11
Total	0.45	0.34
Germany		
ICT sector	4.55	2.28
Non-ICT goods	0.12	0.10
Non-ICT services	0.10	0.06
Total	0.31	0.19
Italy		
ICT sector	2.03	0.49
Non-ICT goods	0.03	-0.01
Non-ICT services	0.02	-0.02
Total	0.10	0.00
Spain		
ICT sector	0.27	0.56
Non-ICT goods	-0.01	0.00
Non-ICT services	-0.05	0.00
Total	-0.03	0.02
UK		
ICT sector	4.22	1.72
Non-ICT goods	0.05	0.15
Non-ICT services	0.02	0.08
Total	0.24	0.15
US		
ICT sector	3.01	2.50
Non-ICT goods	0.16	0.19
Non-ICT services	0.05	0.06
Total	0.19	0.17

A.2 Lists of Countries and Industries

Table A.22: List of Industries

Industry	***NACE 1.1 code***
Agriculture, hunting, forestry and fishing	AtB
Mining and quarrying	C
Food , beverages and tobacco	15,16
Textiles and textile, Leather and footwear	17t19
Wood and of wood and cork	20
Pulp, paper, paper , printing and publishing	21,22
Coke, refined petroleum and nuclear fuel	23
Chemicals and chemical	24
Rubber and plastics	25
Other non-metallic mineral	26
Basic metals and fabricated metal	27,28
Machinery, nec	29
Electrical and optical equipment	30,31,32,33
Transport equipment	34, 35
Manufacturing nec; recycling	36, 37
Electricity, gas and water supply	E
Construction	F
Sale, maintenance and repair of motor vehicles and motorcycles; retail sale of fuel	50
Wholesale trade and commission trade, except of motor vehicles and motorcycles	51
Retail trade, except of motor vehicles and motorcycles; repair of household goods	52
Hotels and restaurants	H
Transport and storage	60to63
Post and telecommunications	64
Financial intermediation	J
Real estate activities	70
Renting of m&eq and other business activities	71, 72, 73, 74
Public admin and defence; compulsory social security	L
Education	M
Health and social work	N
Other community, social and personal services	O

Table A.23: List of Countries in WIOD

Country Name	***Acronym***
Australia	AUS
Austria	AUT
Belgium	BEL
Brazil	BRA
Bulgaria	BGR
Canada	CAN
China	CHN
Cyprus	CYP
Czech Republic	CZE
Denmark	DNK
Estonia	EST
Finland	FIN
France	FRA
Germany	DEU
Great Britain	GBR
Greece	GRC
Hungary	HUN
India	IND
Indonesia	IDN
Ireland	IRL
Italy	ITA
Japan	JPN
Latvia	LVA
Lithuania	LTU
Luxembourg	LUX
Malta	MLT
Mexico	MEX
Netherlands	NLD
Poland	POL
Portugal	PRT
Romania	ROU
Russia	RUS
Slovak Republic	SVK
Slovenia	SVN
South Korea	KOR
Spain	ESP
Sweden	SWE
Taiwan	TWN
Turkey	TUR
United States	USA
Rest of the World	ROW

References

Aulin-Ahmavaara, P. (1999), 'Effective Rates of Sectoral Productivity Change', *Economic Systems Research* **11**(4), 349–363.

Cardona, M., Kretschmer, T. and Strobel, T. (2013), 'ICT and Productivity: Conclusions from the Empirical Literature', *Information Economics and Policy* **25**(3), 109–125.

Gu, W. and Yan, B. (2017), 'Productivity Growth and International Competitiveness', *Review of Income and Wealth* **63**(1), 113–133.

Herrendorf, B., Rogerson, R. and Valentinyi, A. (2014), Growth and Structural Transformation, *in* 'Handbook of Economic Growth', Vol. 2, pp. 855–941.

Hulten, C. (1978), 'Growth Accounting with Intermediate Inputs', *The Review of Economic Studies* **45**(3), 111–118.

O'Mahony, M. and Timmer, M. P. (2009), 'Output, Input and Productivity Measures at the Industry Level: The EU KLEMS Database'.

Oulton, N. (2012), 'Long Term Implications of the ICT Revolution: Applying the Lessons of Growth Theory and Growth Accounting', *Economic Modelling* **29**(5), 1722–1736.

Timmer, M. P. (2017), 'Productivity Measurement in Value Chains', *International Productivity Monitor* **33**, 182–193.

Timmer, M. P., Dietzenbacher, E., Los, B., Stehrer, R. and de Vries, G. J. (2015), 'An Illustrated User Guide to the World Input–Output Database: the Case of Global Automotive Production', *Review of International Economics* **23**(3), 575–605.

Wolff, E. N. (1994), 'Productivity Measurement within an Input-Output Framework', *Regional Science and Urban Economics* **24**, 75–92.