European Commission

The Sectoral Impact of the Digitisation of the Economy

FINAL REPORT

July 28, 2017

A study prepared for the European Commission
DG Communications Networks, Content & Technology
by:

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Zentrum für Europäische Wirtschaftsforschung GmbH
Centre for European Economic Research

Digital Agenda for Europe

European Commission

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This study was carried out for the European Commission by the Centre for European Economic Research (ZEW).

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Contract number: 30-CE-0834589/00-35

SMART 2016/0054

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ISBN number to be added

DOI: number to be added

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ABSTRACT (ENGLISH)

The objective of the study "The sectoral impact of digitisation of the economy" is to assess productivity effects of digitisation at the sectoral level and to deduce employment effects for the EU15, the US, China and Japan for 14 industries for the years 2000 to 2021. Negative substitution effects are moderately larger than positive price and income effects in most sectors. Additionally, productivity increases in ICT production itself contribute positively to employment, such that on average, digitisation has an overall effect close to zero on employment.

ABSTRACT (FRENCH)

L'objectif de l'étude «L'effet sectoriel de la diffusion du numérique dans l'économie» consiste à évaluer les effets de productivité de la diffusion du numérique au niveau sectoriel et à déduire les conséquences pour l'emploi dans l'UE15, les États-Unis, la Chine et la Japon pour 14 secteurs et la période de 2000 à 2021. Les effets de substitution négatifs sont légèrement plus forts que les effets de prix et de revenu positifs dans la plupart des secteurs. Par ailleurs, la croissance de productivité dans le secteur producteur des TIC contribue de manière positive au niveau d'emploi. En conséquence, la diffusion du numérique a un effet agrégé proche de zéro sur l'emploi.

1. EXECUTIVE SUMMARY (ENGLISH)

The objective of the study “The sectoral impact of digitisation of the economy” is to assess the potential of information and communication technologies (ICT) to reduce prices (through increased productivity) by sector, to estimate the effect on demand for goods and services in each sector at these lower prices (based on price elasticities) and deduce potential employment impacts.

With more investment into digital technologies, employment at the sectoral level changes as a result of three factors:

(1) the substitution of labour by ICT at constant output (measured by the partial elasticity of substitution between factors)

(2) the increased demand for output and factor input due to lower product prices resulting from digitisation (measured by the price elasticity of product demand)

(3) the increased demand for output and factor input due to increased income available to agents as a result of digitisation (measured by the income elasticity of product demand).

The study covers 12 countries and 14 industries. Out of the EU15 countries, nine are covered in the database. The effects are extrapolated to give the aggregate of all EU15 countries.

The study estimates the relevant elasticities based on data for the years 1995 to 2007 available in the NACE1 sector classification. The effects of digitisation are extrapolated for the period 2000 to 2021 using data in the NACE2 classification which are available for most countries up to the year 2014.

The methodological review which precedes the quantitative analysis covers in detail, among others, a study by the OECD (2016). The objective and fundamental approach of that study and the present one are similar, but the studies differ in terms of the methodology and the data employed. Consequently, the results also differ to a certain extent.

Following the approach used in OECD (2016), the key variable of our analysis is the elasticity of labour demand with respect to the ICT user cost. This elasticity is composed of the three effects mentioned above (substitution, price effect and income effect). If the user cost of ICT decreases, the use of ICT capital in production increases. In general, a certain fraction of labour is substituted as a result. In addition, the product prices decrease and the revenues of the economic agents increase. This has a positive effect on labour demand.

To ensure that the effect which is measured only reflects investment in ICT that has actually been undertaken, the analysis does not consider the actual decline in ICT user cost but the decline projected by the model for the actually observed ICT investment.

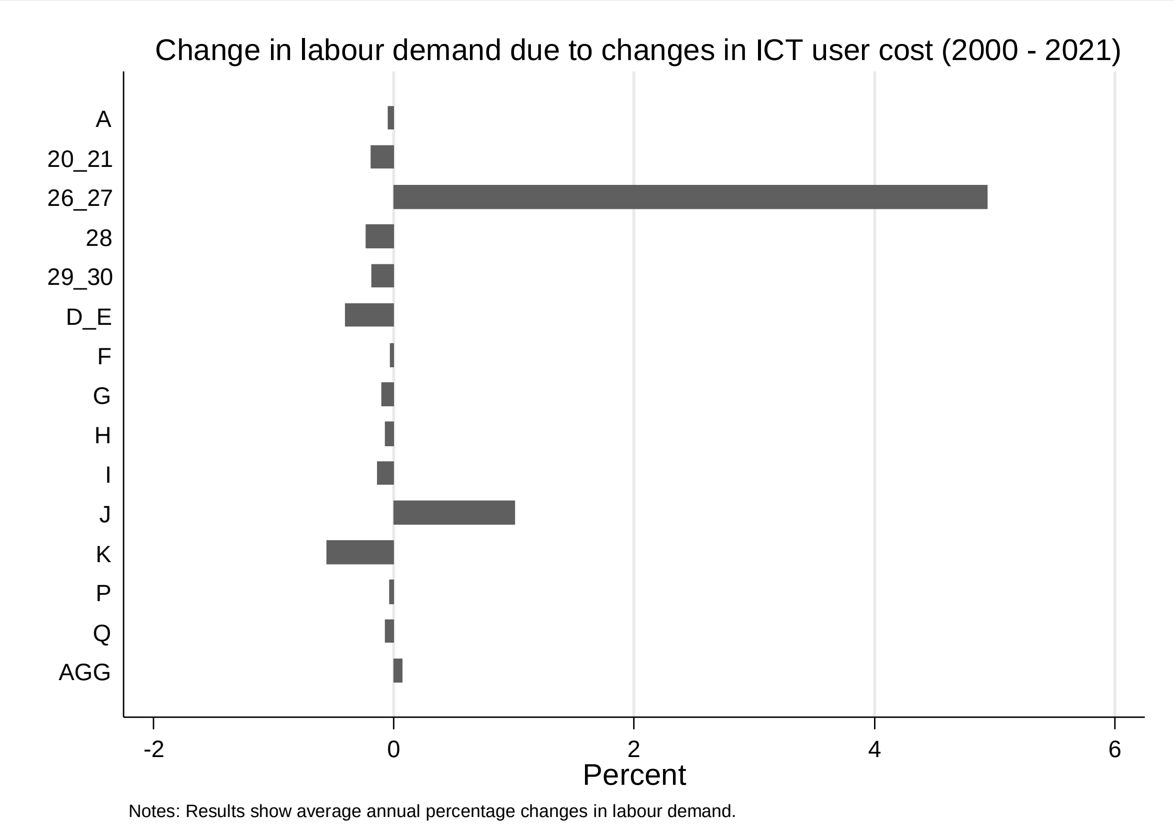


Figure 1: Annual change in labour demand due to changes in ICT user cost (between 2000 and 2021), percent

The elasticity of substitution between ICT and labour is determined based on a translog production function estimation. The demand elasticities are determined based on the estimation of sectoral demand functions.

In the sectors that produce ICT, the effect of total factor productivity growth on labour demand is included in the calculation of the effect of digitisation on labour demand.

Figure 1 shows the net effects of a change in (projected) ICT user cost on labour demand. For the ICT-producing sectors, this includes the effect of total factor productivity growth.

In all sectors, the annual negative effect is lower than 0.5 percent. The sector that produces ICT equipment (NACE2 26/27) exhibits a positive effect of about 4 percent. For all countries and sectors analysed taken together, the aggregate effect visible in Figure 1 is close to neutral. This is, however, not a result inherent in the modelling assumptions but a result depending on the particular empirical estimates.

Figure 2 translates the relative effect into a number of jobs (expressed in full-time equivalents) in the NACE2 sectors and for the aggregate of the sectors and countries covered. The countries covered are nine EU countries (Austria, Finland, France, Germany, Italy, Netherlands, Spain, Sweden and the United Kingdom), the US, China and Japan. On the negative side, the model estimates a total job loss of 15 million between 2000 and 2021 in the non-ICT sectors. On the positive side, it estimates a creation of around 30 million jobs in the ICT hardware sector (NACE2 26/27) and of several millions in the ICT services sector (NACE2 J).

The precise result is dependent on methodological choices that will continue to be debated in this area of research. It is possible that the effect of total factor productivity growth in sector 26-27 is in reality weaker. Since the observed employment change in sector 26-27 is negative in all countries except China, the strong positive effect found here has to be considered with caution.

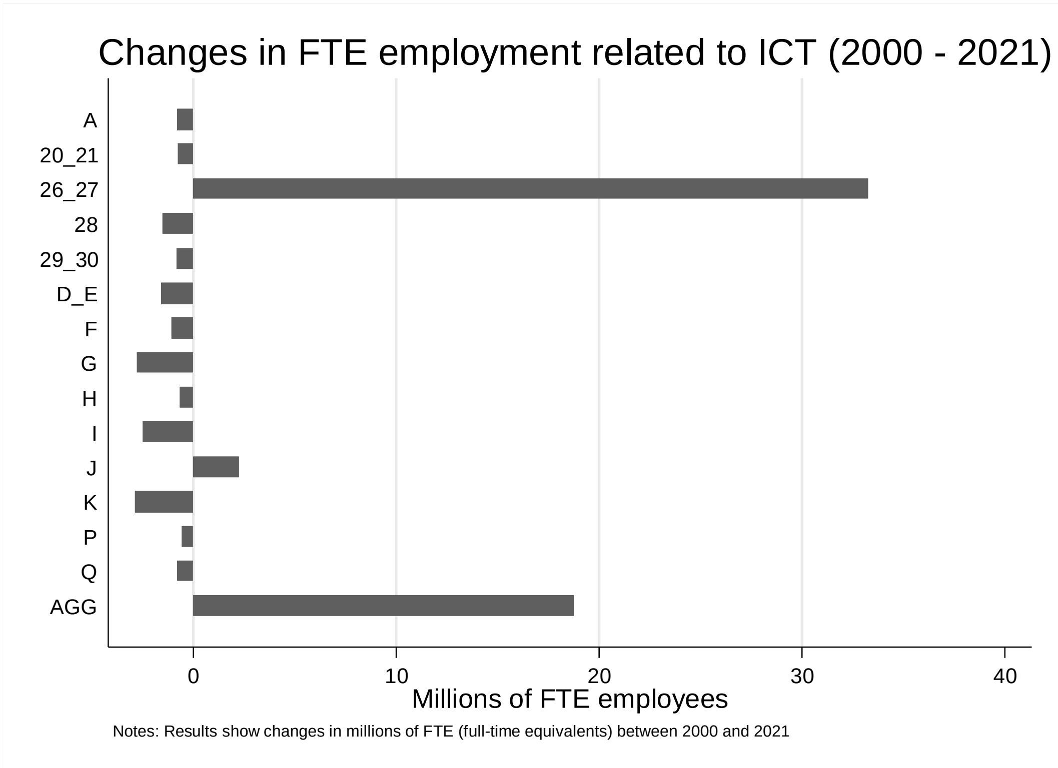


Figure 2: Changes in employment related to ICT (between 2000 and 2021) in millions of FTE

In Figure 3, we summarise the predicted employment effects related to ICT and compare them to actual employment changes. In China, more than 40 million jobs are created (or expected to be created in the coming years) by 2021 and the model predicts that slightly less than 20 million are to be created due to digitisation. This positive effect results from TFP growth in the production of electrical and optical equipment. In the US we see that digitisation has a small positive effect on overall employment. The effects of digitisation in the EU15 region and in Japan can be considered neutral when compared to actual employment change. Again, TFP growth in the ICT sector leads to job creation while all other sectors display moderate job loss.

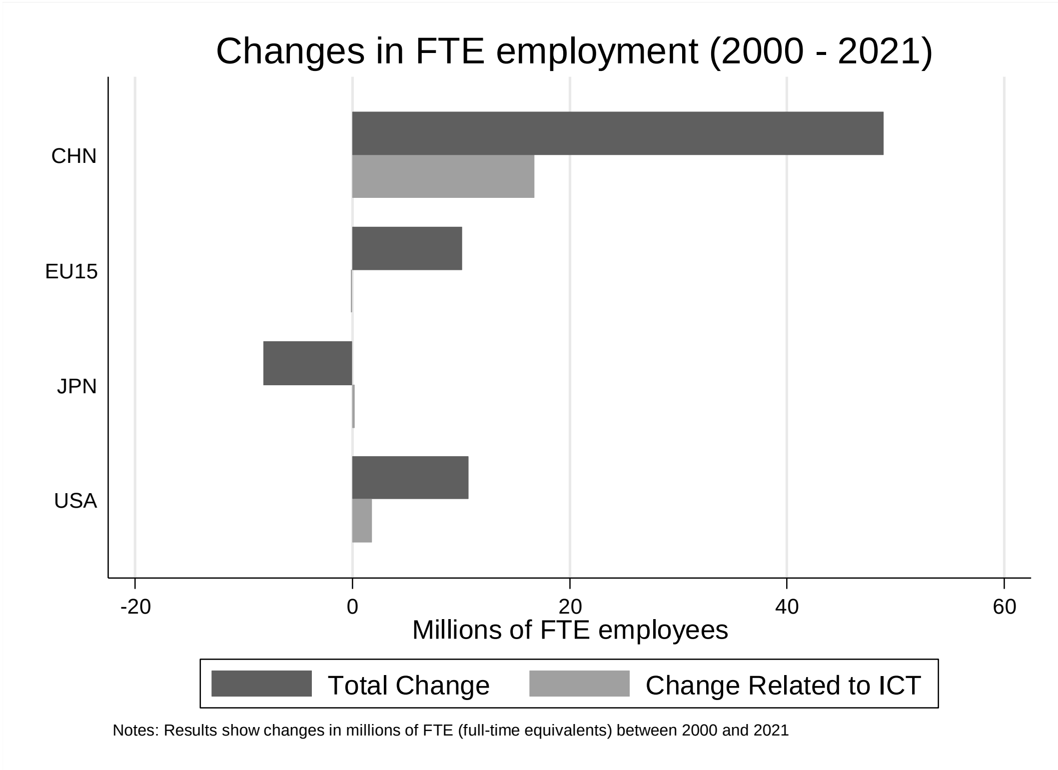


Figure 3: Total changes in employment and changes in employment related to ICT (between 2000 and 2021) in millions of FTE

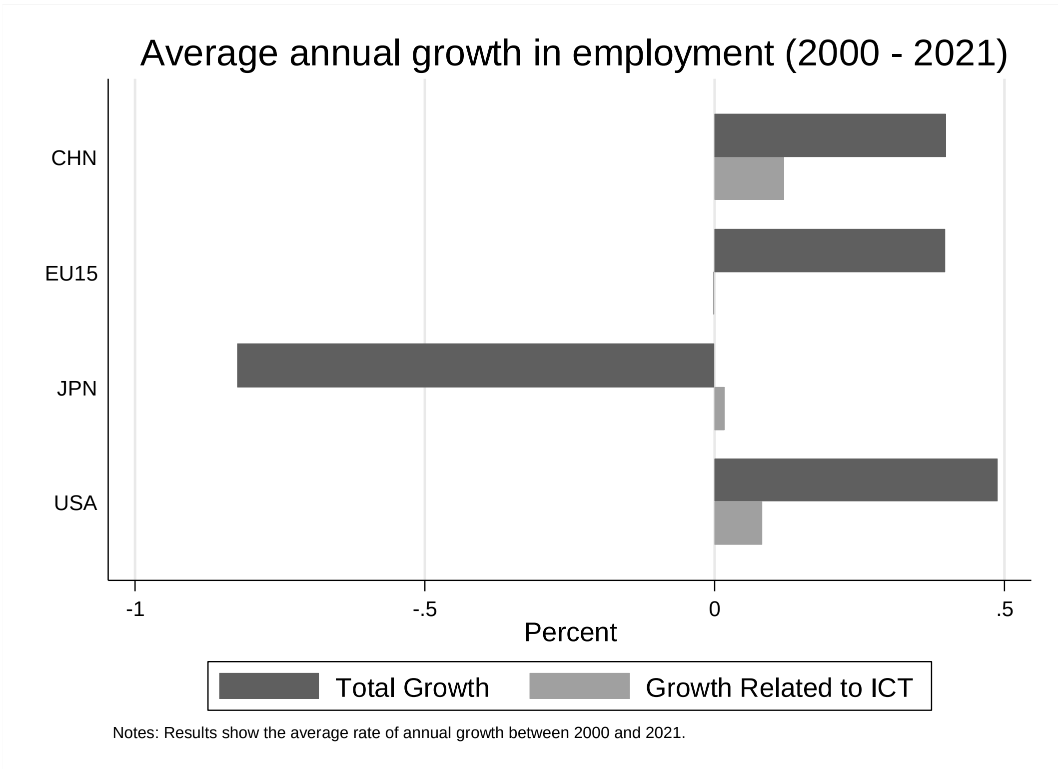


Figure 4: Annual change in labour demand due to changes in ICT user cost (between 2000 and 2021), percent

Figure 4 expresses the same employment effects in relative terms. The positive effects for China and the US are now of similar magnitude.

In sum, this study underlines that a reallocation of jobs across sectors in the process of digitisation is more likely than a net job loss of a significant magnitude. The way the TFP influence is modelled should be refined in future research.

2. EXECUTIVE SUMMARY (FRENCH)

Les objectifs de cette étude sur l'effet sectoriel de la diffusion du numérique dans l'économie consistent à évaluer le potentiel des TIC (technologies d'information et de communication) de réduire les prix de produits (par une productivité augmentée), à estimer l'effet sur la demande des produits (basé sur l'élasticité-prix de la demande) et à en déduire les conséquences pour le niveau d'emploi au niveau sectoriel.

Avec un investissement croissant dans les technologies numériques, l'emploi change au niveau sectoriel en raison de trois facteurs:

(1) une substitution de travail par les TIC à niveau de production constant (mesurée par l'élasticité de substitution)

(2) une demande de produits et de facteurs de production plus élevée en conséquence de la baisse des prix résultant de la digitalisation (mesurée par l'élasticité-prix de la demande)

(3) une demande des produits et des facteurs de production plus élevée en conséquence d'une hausse du revenu résultant de la digitalisation (mesurée par l'élasticité-revenu de la demande).

Pour analyser ces effets, l'étude couvre 12 pays et 14 industries. Parmi les pays de l'UE15, neuf sont inclus dans la base de données. Les effets sont extrapolés pour l'agrégat des pays de l'UE15.

L'étude estime les élasticités à partir de données pour les années 1995 à 2007 disponibles dans la classification des secteurs NACE1. Les effets de la digitalisation sont extrapolés pour la période de 2000 à 2021 en utilisant des données de la classification NACE2 qui sont disponibles pour la plupart des pays jusqu'à l'année 2014.

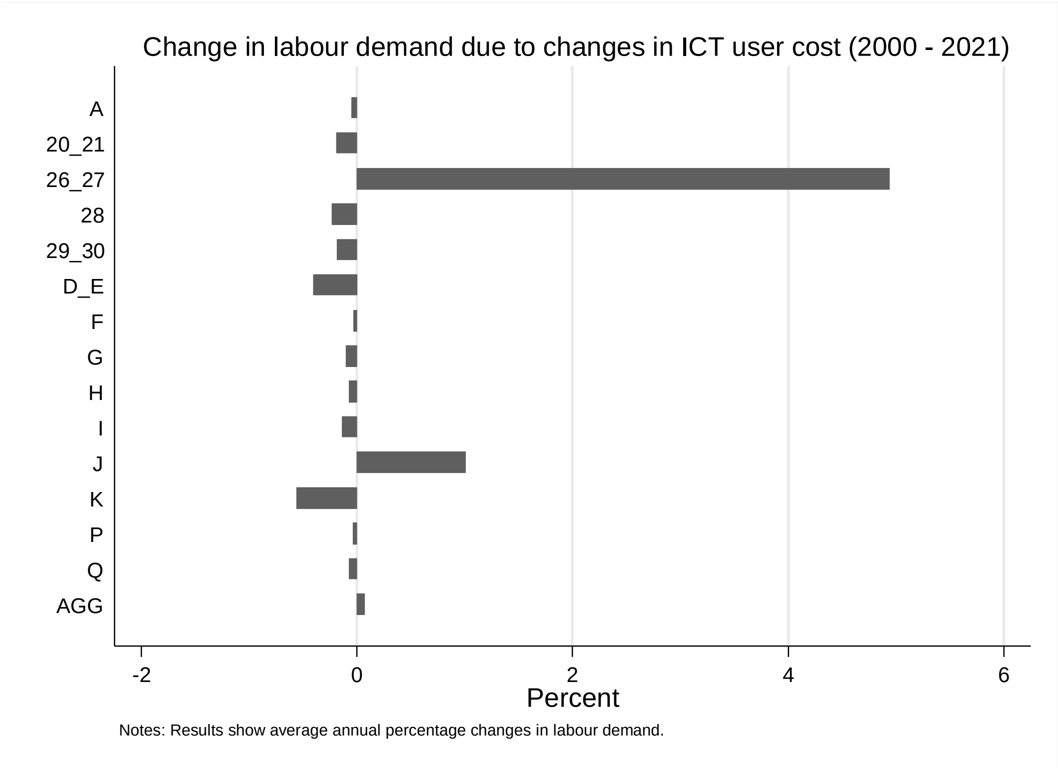
La revue méthodologique qui précède l'analyse quantitative couvre entre autres en détail une étude de l'OCDE (2016). Poursuivant un objectif et une approche fondamentale similaires, les deux études se distinguent au niveau de détails qui concernent à la fois la base de données utilisée et la méthodologie. En conséquence, les résultats obtenus révèlent également des différences.

Suivant l'approche de l'OCDE (2016), la variable clé de l'analyse quantitative de notre étude est l'élasticité de la demande de travail par rapport au coût d'usage des TIC. Cette élasticité est composée des trois effets mentionnés ci-dessus (substitution, effet prix et effet revenu). Si le coût d'usage des TIC baisse, l'usage de capital en TIC augmente. Généralement, une partie du travail est substituée en conséquence. Par ailleurs, les prix des produits baissent et les revenus augmentent, ce qui a un effet positif sur la demande de travail. Pour assurer que l'effet ne reflète que des investissements qui ont été effectués, l'analyse ne considère pas la baisse actuelle du coût d'usage des TIC mais la baisse projetée par le modèle pour l'investissement en TIC qui a été observé.

L'élasticité de substitution entre les TIC et le travail est déterminée à partir d'une estimation d'une fonction de production translogarithmique. Les élasticités de la demande sont déterminées à partir d'une estimation de fonctions de demande sectorielle.

Dans les secteurs produisant les TIC, l'effet de la croissance de la productivité globale des facteurs sur la demande de travail est rajouté pour calculer l'effet agrégé de la digitalisation sur la demande de travail.

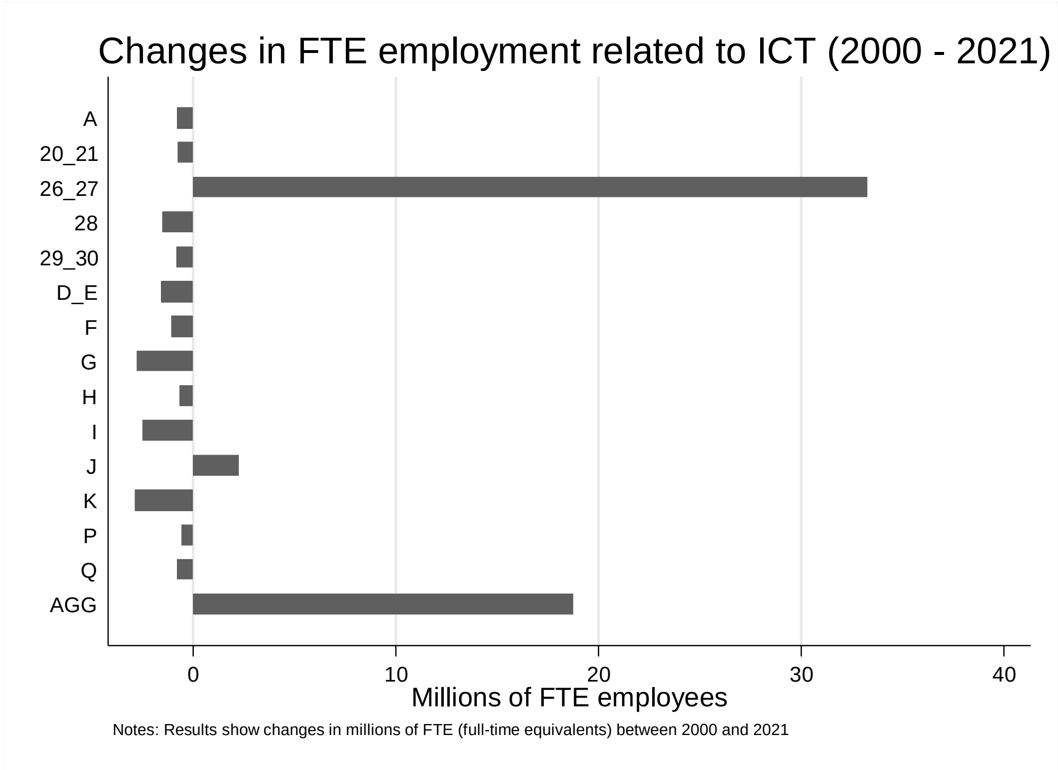
Le graphique 1 montre les effets annuels nets du changement du coût d'usage des TIC sur la demande de travail. Pour les secteurs producteurs des TIC, l'effet de la productivité globale des facteurs a été rajouté.



Graphique 1

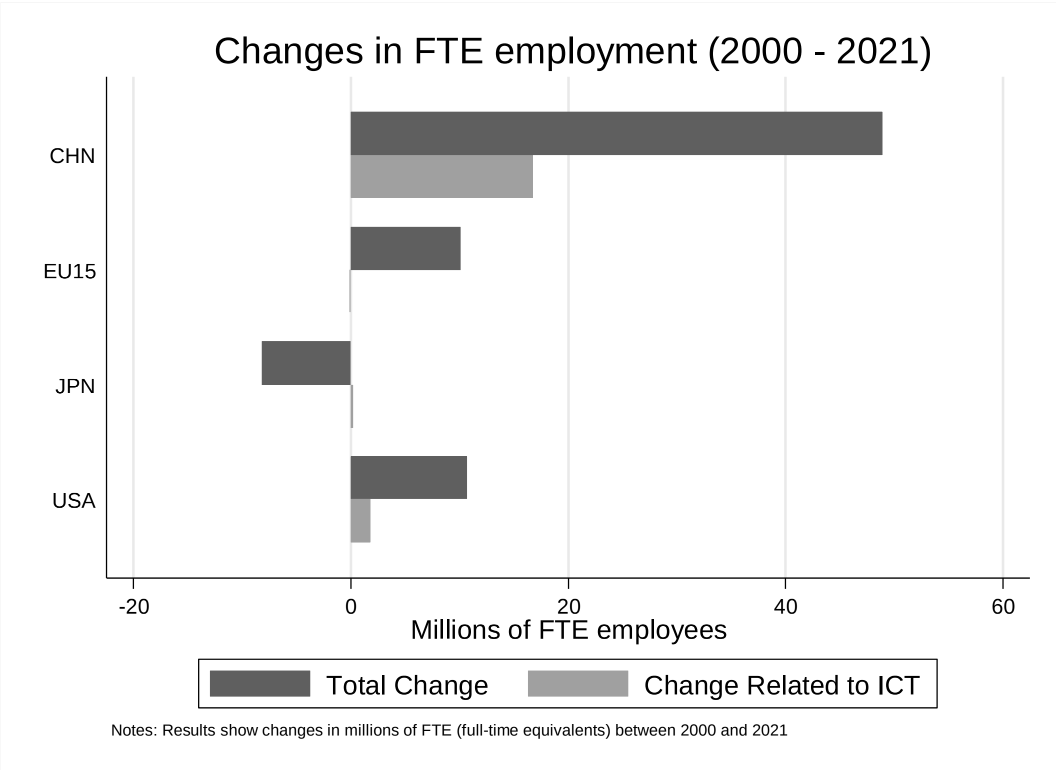
Dans tous les secteurs, l'effet annuel négatif est inférieur à 0.5 pourcent. Le secteur produisant de l'équipement en TIC (NACE2 26-27) présente un effet positif d'environ 4 pourcent. Celui-ci résulte de la croissance de la productivité globale des facteurs. Pour le total des pays et secteurs analysés, l'effet agrégé est proche de zéro. Ceci ne résulte cependant pas des hypothèses du modèle mais des effets empiriques estimés.

Le graphique 2 traduit l'effet relatif en nombre d'emplois (exprimé en équivalent de plein temps) dans les secteurs de la classification NACE2 et pour l'agrégat de tous les secteurs inclus dans l'étude. Les pays couverts sont neuf pays de l'Union Européenne (l'Allemagne, l'Autriche, l'Espagne, la Finlande, la France, le Royaume-Uni, l'Italie, les Pays-Bas et la Suède), les États-Unis, le Japon et la Chine. Du côté négatif, le modèle estimé indique la perte d'environ 15 millions d'emplois dans les secteurs non-numériques. Du côté positif, il indique la création de plus de 30 millions d'emplois dans le secteur produisant de l'équipement en TIC (NACE2 26-27) et de plusieurs millions d'emplois dans le secteur des services d'information et de communication (NACE2 J).



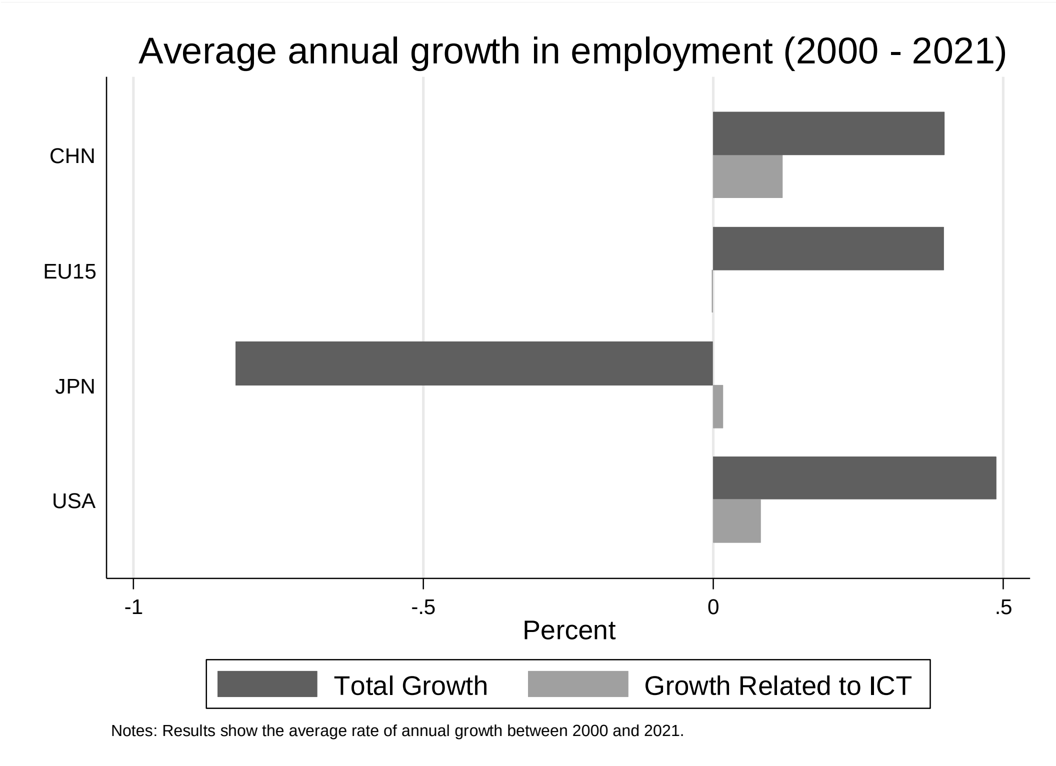
Graphique 2

Le résultat précis dépend de choix méthodologiques qui vont continuer à être discutés dans la recherche sur les effets de la digitalisation. Il est possible que l'effet de productivité globale des facteurs positif dans le secteur 26-27 soit en réalité moins fort. Puisque l'évolution réelle de l'emploi dans le secteur 26-27 est négative dans tous les pays sauf la Chine, l'effet doit être interprété avec précaution.



Graphique 3

Le graphique 3 présente une comparaison des effets de la digitalisation sur l'emploi avec l'évolution actuelle de celui-ci. En Chine, plus de 40 millions d'emplois vont être créés dans la période de 2000 à 2021 comparé à un effet positif de 20 millions lié digitalisation. Cet effet positif résulte de la croissance de la productivité globale des facteurs dans la production des TIC. Aux Etats-Unis, on observe un effet positif plus faible. Comparé à l'évolution actuelle de l'emploi, les effets dans l'UE15 et au Japon sont pratiquement neutres. La croissance de la productivité globale des facteurs dans le secteur des TIC mène à la création d'emplois pendant qu'une diminution modérée d'emplois est observée dans tous les autres secteurs.



Graphique 4

Le graphique 4 exprime le même effet en termes relatifs. Les effets positifs aux États-Unis et en Chine ont maintenant une dimension similaire.

En somme, notre étude souligne qu'une réallocation sectorielle d'emplois au cours de la diffusion du numérique est plus probable qu'une baisse nette importante d'emplois. Puisque l'évolution actuellement observée de l'emploi dans le secteur 26-27 est négative dans tous les pays sauf la Chine, l'effet positif fort dans ce secteur doit être considéré avec précaution. Vue son ampleur, la recherche devrait se consacrer à une modélisation plus élaborée de l'effet de la productivité globale des facteurs sur l'emploi dans l'avenir.

3. METHODOLOGY

3.1. Objective of the study

The study assesses the potential of information and communication technologies (ICT) to reduce prices (through increased productivity) by sector, estimates the effect on demand for goods and services in each sector at these lower prices (based on price and income elasticities) and deduces potential employment impacts. The study also takes counteracting substitution effects between ICT and labour into account. The overall objective of the study is to support the following policy objectives: Results will feed the justification and the problem definition of related policies and will help strengthening the Commission's narrative on digital skills and digital employment policies. In particular, the study sheds light on the sectoral dimension of employment effects and compares effects observed in major EU countries with effects in other major economies.

3.2. Review of previous studies

3.2.1. Review of previous studies on productivity effects of ICT

In order to identify the most appropriate methodology for our study, we first summarise several studies that we consider to be most closely related to ours in analysing macroeconomic productivity effects of ICT, paying particular attention to their sectoral heterogeneity. We then refer to further studies that contain relevant insights for particular aspects of our study while focusing on different research questions.

The most relevant previous studies on the productivity effects of ICT at the sectoral level are in our view Cardona et al. (2013) and Inklaar et al. (2005). Although it does not comment in detail on individual sectors, another useful recent study is Dimelis and Papaiouannou (2011). Full references to all studies are given in the literature section.

Cardona, Kretschmer and Strobel (2013). ICT and productivity: conclusions from the empirical literature

Research design: The study is a meta-survey covering around 150 original studies. It presents research designs and results that have proven robust over a large number of studies, at the same time highlighting the existence of a variety of methods and remaining uncertainty about empirical effects. The paper is interested in two questions: first, in the evidence on the size and quantitative range of the ICT effect on productivity, and second, in evidence on the so-called general purpose technology hypothesis. We are mainly interested in the first question.

Database: The study does not have a direct empirical database but it covers original empirical research using different databases at the macro, sectoral and firm level.

Methodology: The survey covers studies using economic output measures as outcome variables for assessing productivity. It distinguishes between studies using non-parametric approaches, primarily growth accounting techniques, and parametric approaches, primarily econometric estimations of production functions. Concerning the level of aggregation of the data, the survey considers country level, industry level and firm level studies. Moreover, it distinguishes between different ICT measures used in the original research, including measures of ICT investment and narrower measures, such as investment in telecommunications equipment. In total, 73 studies at the macro or country level, 38 studies at the industry level and 47 studies at the firm level are considered.

In their most basic variant, empirical studies using both growth accounting and econometric estimation assume a neoclassical production function with constant returns to scale and perfect competition. Both approaches empirically determine the output elasticity of inputs. This elasticity indicates, e.g., by how much labour productivity increases if ICT capital services per unit of labour increase by one percent. In a production function approach, growth in labour productivity that cannot explained by input growth via the output elasticity is considered as total factor (TFP) productivity growth. In growth accounting, it is computed as a residuals number. In econometric estimation, it is reflected by time trends included and the error term. The level of TFP for each unit of observation may be reflected in further unit-specific control variables. Problems discussed by Cardona et al. (2013) include the omission of relevant variables to explain TFP, unmeasured intangible assets and endogeneity in econometric estimation. They also underline that data quality is essential for determining the parameters of a production function empirically. Results from growth accounting studies are expressed as a percentage contribution to labour productivity growth by aggregate ICT investment and by TFP in the ICT sector. Results from econometric studies are summarised by reporting output elasticities of ICT. In Saam (2014), we argue that both variants of representing contributions to productivity growth can be in fact used with both empirical approaches.

Results: Growth accounting studies for EU countries and the US find ICT contributions to labour productivity growth ranging between 17 per cent in a study covering the EU over the years 1990-1995 to over 60 per cent in a study covering the US for the years 1995-2000. This includes TFP growth in the ICT-producing sector.

In econometric estimations, output elasticities of ICT cluster around 0.05 to 0.06, but with large positive and negative outliers. The elasticity is increasing over time, but no systematic association with the level of aggregation of the studies could be detected. Inclusion of fixed effects generally results in a more conservative estimate.

Lessons learnt: The paper by Cardona et al. (2013) allows us to verify that our methodological choices are in line not just with a small number of papers but with the majority of research on ICT contributions to productivity growth. It also gives a good overview of methodological problems associated with research on productivity effects of ICT. Moreover, the paper indicates the range of empirical results found in earlier research and makes some reference to sectoral heterogeneity in these results, although this is only very briefly covered. Important measurement and methodological issues discussed in this paper are (1) the difficulty of separating quality improvement in ICT appropriately from TFP growth, (2) the omission of intangible investment, (3) variable factor utilization and lagged adjustment, (4) imperfect competition and non-constant returns to scale.

In addition, the paper mentions that the frequently used Cobb-Douglas function is too restrictive for some issues of interest when analysing productivity effects of ICT. We consider this to be the case in our setting, where different degrees of substitution between labour and ICT matter, and therefore opt for a more general translog production function.

Inklaar, O'Mahony and Timmer (2005). ICT and Europe's Productivity Performance: Industry-level Growth Account Comparisons with the U.S.

Research design: This is one of many growth accounting papers that were written as part of or after the EU KLEMS project, which allows international productivity comparisons, including the analysis of productivity effects of ICT, to an extent that was previously not possible. The paper investigates the productivity growth differential observed at the time between the U.S. and Europe and the role ICT investment and ICT intensive industries play in generating this differential. We choose this earlier paper since it focuses on the contribution of ICT at the sectoral level, while other papers focus more on the contribution of ICT at the aggregate level or at the sectoral composition of aggregate productivity growth. More empirical results at the sectoral level can also be found in our own paper (Niebel and Saam, 2016).

Database: Data for five countries (France, Germany, Netherlands, United Kingdom, United States) for the years 1979 to 2000 from the Groningen Growth and Development Database are used. In particular, data for ICT capital services are constructed.

Methodology: The paper uses the standard growth accounting methodology, paying particular attention to issues of aggregation.

Results: The main result of interest for our own study is the contribution of industry ICT capital deepening to labour productivity growth. Sectors with both a high ICT contribution and a large gap between the U.S. and the EU-4 countries in the period from 1995 to 2000 were financial intermediation, trade and the ICT hardware sector. The measured gap was also large in non-market services and social and personal services. In business services, the European countries displayed a higher ICT contribution. Overall, the paper finds that ICT-intensive services experienced both a higher ICT productivity effect and higher TFP growth in the U.S. after 1995 than in the European countries.

Lessons learnt: The paper shows the quantitative range of the ICT contributions at the sectoral level, but also highlights that TFP growth in ICT intensive services is no less important. Although it seems natural to assume ICT-based innovation driving TFP growth differentials in ICT-intensive sectors, this and other studies (such as Cardona et al., 2013) highlight that it is hard to empirically relate TFP growth to ICT investment.

Dimelis and Papaioannou (2011). ICT growth effects at the industry level: A comparison between the US and the EU

Research design: The study revisits some of the relations investigated by Inklaar, O'Mahony and Timmer (2005) using an econometric panel data approach.

Database: Data from the Groningen Growth and Development Centre for 26 industries in the US and four major EU countries from 1980 to 2000 are used. The database is very similar to the one in Inklaar, O'Mahony and Timmer (2005).

Methodology: A Cobb-Douglas production function is estimated from a single equation. Two alternative econometric methods are employed, a System-Generalized-Method-of-Moments (SYS-GMM) approach, which accounts for the potential endogeneity of ICT, and a panel Error Correction Model using a Pooled Mean Group estimator. The Error Correction Model is in some respects preferable to the SYS-GMM approach if both the number of cross-section units and the time span are large and of the same order of magnitude. It can be applied to cointegrated variables. This method make is possible to disentangle long-run from short-run effects. A Pooled Mean Group estimator is used, which imposes a common long-run relationship while allowing for differential short-run dynamics.

Results: The SYS-GMM results suggest that a strong ICT effect on productivity in the EU became weaker after the early 90s whereas it saw an increase in the US in the late 90s. Moreover, the productivity effects of ICT seem concentrated in industries that are ICT producers or heavy ICT users.

Lessons learnt: The paper revisits an important result on the sectoral concentration of ICT productivity effects from growth accounting studies and illustrates the application of different econometric approaches.

Further studies

Since EU KLEMS is constructed at the sectoral level, sectoral heterogeneity is inherent in many growth accounting papers based on the EU KLEMS data. However, most papers are not interested in displaying the difference of ICT contributions by sector and country. We have to underline here that the reason for this lack of sectoral results is not due to a lack of methods nor data, but the fact that the main focus of the majority of papers is on aggregate ICT effects or on total sectoral contributions to aggregate labour productivity growth, which are not broken down by factors of production.

In addition to the papers described in detail we have been looking at further econometric studies which reveal how the productivity effects of ICT investment vary by sector (i.a., O'Mahony and Vecchi, 2005; Acharya, 2016). The number of observations available in sectoral data sets makes it difficult to identify different output elasticities in different sectors in a robust way. Acharya (2016) comments on the fact that the mean group estimator, one kind of panel estimator that allows for sectoral heterogeneity, provides reliable panel averages for coefficients, while individual coefficients for country-industry combinations produced by the method are unreliable unless the time span is large. Growth accounting, which directly equates output elasticities to factor shares, is able to produce sectoral results more easily, though it, of course, also requires stronger assumptions.

3.2.2. Review of previous studies on effects on prices, product demand and labour demand

Although the productivity and employment effects of ICT have been widely analysed in recent years, the precise channel lying at the heart of this study has not been the subject of many previous studies. In most studies, either productivity effects or employment effects have been quantified, but not both at the same time, even though one conditions the other. The present study has the aim of linking the explicit quantification of the channel from more ICT investment to lower product prices and, ceteris paribus, higher labour demand resulting from decline in relative product prices and increases in income.

The study most closely related to ours is by the OECD (2016). We also comment on the studies by Gregory et al. (2016) and Blien and Ludewig (2016). After the analysis in this paper had been carried out,

Previous studies have also focused to a large extent on the substitution of routine labour tasks by ICT and on changes in employment by skill level. However, the main variable of interest in our study is sectoral labour input, without a decomposition by tasks and skill levels.

OECD (2016): ICT and Jobs – Substitutes or Complements?

Research design: The study uses international macroeconomic and sectoral data to estimate the effects of ICT investment on employment from standard labour and product demand theory. Results are reported for selected OECD countries over the years 1995-2012.

Database: The data mainly come from different OECD sources: the STAN database, the Annual National Accounts database, the Productivity Database and the Trade in Value Added database. Data on productive capital by sector and asset type from the Dutch growth accounts is used to derive the share of ICT in total capital services by sector in all countries. In total, the sectoral analysis covers 10 sectors and 18 countries, mostly for the years 1995 to 2012.

Methodology - modelling: The paper models both aggregate and sectoral labour demand from standard factor demand theory based on minimisation of a cost function. It models product demand using a quadratic almost ideal demand system (QAIDS). The exogenous driver of increasing digitisation of the economy in their approach is the declining user cost of ICT capital services. Assuming a neoclassical cost function, three partial derivatives (in logarithmic terms, to reflect percentages) are taken in order to compute the total effect of declining ICT user cost on employment:

- the partial elasticity of employment with respect to ICT user cost, holding output and other input prices constant (also called cross-price elasticity of labour demand with respect to ICT user cost)
- the partial elasticity of unit product cost with respect to ICT user cost holding inputs and other factor prices constant and
- the partial elasticity of the product price with respect to ICT user cost, holding inputs and other factor prices constant. The latter differs from the former because of monopolistic rents.

The key equation relevant for the sectoral results is the following:

$$\frac{\partial ln\, H}{\partial ln\, uc_{IT}} = c_{IT}\sigma_{H,IT} - \varepsilon(1 - s_M)c_{IT} + \eta(-s_M c_{IT})$$

with H labour input, uc_{IT} the user cost of ICT capital, c_{IT} cost share of ICT capital equalling the output elasticity of ICT, $\sigma_{H,IT}$ the partial elasticity of substitution between labour and ICT capital, ε the elasticity of final demand to prices, s_M the share of monopolistic rents in total value added, η elasticity of final demand to income. The first product, equalling the cross-price elasticity between labour and ICT user cost, is estimated from a labour demand equation derived from a production function. The other two elasticities are estimated from product demand equations. The income shares are empirically observed.

While substitution between ICT and labour has an effect on labour demand at constant output (first term in equation), lower prices and higher monopolistic rents (additional income available in the economy) only affect labour demand if production changes (second and third term). For the aggregate economy, lower costs raise demand one-to-one, since they result in higher real income (irrespective of the split between monopolistic rents and lower product prices). So for the aggregate economy, the effect of ICT investment on labour demand depends on whether the substitution effect is larger or lower than one. At the sectoral level, however, the price and the income elasticity of demand may be different from one. This is the main effect of interest that is evaluated in the study.

To evaluate the three effects of the above equation at the sectoral level, the study estimates a factor demand equation derived from a production function and a system of product demand equations. It then combines the estimated elasticities to derive the total employment effect of ICT at the sectoral and the aggregate level.

To our knowledge this is the only study estimating a production function at the sectoral level with the aim of studying the sector-specific employment effects of ICT investment. The specific functional form estimated is the labour demand equation (with labour per real value added as a dependent variable) resulting under cost minimisation from a Generalized Leontief production function. The equation relates relative labour demand (equivalent to the inverse of labour productivity) to the relative cost of ICT capital and labour and the relative cost of non-ICT capital and labour.

The central parameter gained from the labour demand equation for the evaluation of the main equation (see above) is the cross-price elasticity between labour and ICT user cost. This is equal to the product of the ICT output elasticity and the partial elasticity of substitution between ICT and labour. This elasticity represents the substitution effect and varies across countries, industries and time. The price and the income elasticity of product demand are estimated from a so-called Almost Ideal Demand (AIDS) system. This is a system of demand equations that is compatible with the theory of consumer demand under very general conditions (the generality of conditions is ‘almost ideal’). In particular, it requires that the demand predicted by equations for particular goods has to add up to the total nominal income available for consumption. In estimating the demand system, the authors differentiate between domestic and export demand.

The parameters and share values of the main equation together determine whether the overall effect of ICT investment on sectoral labour demand in any particular country, sector and year is positive or negative. It has to be multiplied by actual decrease in user cost during this year to obtain the magnitude of the effect.

The employment effect of ICT is also estimated for the aggregate economy. The aggregate effect is thus not only evaluated by adding up all sectoral effects but is also independently estimated using an econometric approach. As emphasized above, the aggregate demand effect of ICT is known in theory, and the only elasticity that affects the overall employment impact in this situation is the elasticity of substitution between ICT and labour. If this elasticity is equal to one, the demand effect and the substitution effect compensate each other and ICT investment has a neutral employment effect. The partial elasticity of substitution between ICT and labour is estimated from the labour demand equation that results from a translog cost function. A lagged dependent variable is introduced in order to reflect lagged adjustment of factor input to changes in factor prices.

Methodology – econometric issues: Econometric estimation with macroeconomic data poses challenges with regard to the endogeneity of the dependent variable and with regard to patterns of correlation over time. The specific solutions proposed in the paper are (1) a Generalized-Method-of-Moments (GMM) estimator applied to a single labour demand equation with two lags of the dependent variable for the aggregate labour substitution and (2) a System Generalized-Method-of-Moments estimator applied to a single labour demand equation derived from a Generalized Leontief production function with two lags of the involved variables at the sectoral level.

The aggregate equation is estimated in differences for the dependent variable (labour cost share) and levels in the explanatory variables (all factor prices). The sectoral equation is estimated in differences.

Results: The OECD study contains various interesting results. We are concentrating here on the results for each sector, commenting only briefly on results for the aggregate economy and neglecting results by skill level. The substitution effect crucially depends on the cross-price elasticity between labour and ICT user cost. The higher the value of the cross-price elasticity the more strongly labour demand declines in response to cheaper ICT. The average sectoral values of the cross-price elasticity found by OECD (2016) vary between the lowest value of 0.05 in the culture, recreation and other services industry and around 0.25 in manufacturing, which is by far the largest value. The second largest is observed in the ICT sector and then in declining order in business services, agriculture (which, as well as manufacturing, exhibits large variation in individual elasticities), the sector comprising trade, transport and accommodation, energy, financial institutions, government and care and construction. Due to large variation, in half of the sectors the average cross-price elasticity is not statistically different from zero. This result summarised in a figure (Figure 9) is very useful for comparison to the results we produce on the substitution effect.

Price and income elasticities estimated from a QUAIDS demand system are also reported. Price elasticities are estimated for both domestic demand and exports, with export demand elasticities clustering very closely around one and domestic elasticities exhibiting greater sectoral variation between 0.8 and 1.2. The estimated income elasticities vary in the same range. The main results on the income elasticity are highlighted as follows: “Agriculture, construction and manufacturing are the only three sectors where income elasticity is below 1” (p.22). On price elasticities, the report summarises: “As for price elasticity, a decrease in price is associated to a more than proportional increase in both domestic demand and exports of financial services and construction. In all other sectors, the price elasticity of exports is below unity. This holds also for domestic demand in manufacturing, culture, recreation and other services, government and care, trade, transport and accommodation, as well as energy.” (p.22).

The overall effect computed from inserting these elasticities in the main equation is reported at the country-sector level for the years 1995-2012. It aggregates negative substitution effects with negative and positive demand effects. The result is reported as follows: “[I]n most countries, demand effects outweigh substitution effects in culture, recreation and other services, construction, and, to a lesser extent, government and care, energy and agriculture, thus leading to a decrease in labour demand particularly in manufacturing, business services and trade, transport and accommodation.” (p.22). The figures per country show that sectoral variation is much higher than variation between countries (which of course depends on the assumption of sector-specific functions). Moreover, the negative effects (in percentages) in some sectors are much larger than the positive effects in others. Employment effects at the sectoral level are reported as percentages, not in terms of the number of jobs.

OECD (2016) estimates aggregate employment effects directly. This means that the sectoral results are not summed up for the aggregate effect, but directly estimated from an aggregate labour demand equation. The study finds the overall aggregate employment effect to follow a dynamic pattern (first turning from positive to negative and then approaching zero in the long-run). The maximal positive or negative employment effect that may temporarily occur following a five percent decrease in ICT user cost is below 0.1 percent. In interpreting this effect, one has to take into account that the average yearly decline in ICT user cost has exceeded five percent in many countries.

Lessons learnt: Since no other study has looked in similar detail at sectoral employment effects of ICT decomposed into substitution, product price and income effects, the results represent the first benchmark results for our own study. We follow a similar overall approach, while making some different methodological choices. In particular, we aim at explicitly highlighting the nexus between sectoral labour productivity and employment effects, whereas the OECD study does not comment on the productivity effects implicit in its modelling.

Information on the level of ICT capital services is not employed in the estimation of the production function in this study; only user cost data is needed. While this is a valid procedure if user cost equals marginal productivity of ICT, any deviation from this assumption or measurement error in ICT user cost strongly affects the ability of this kind of equation to capture the effect of higher ICT investment on employment. Still, declining user cost of ICT is, even in the presence of some misspecification and measurement errors in the demand equation, without doubt a major driving force behind higher ICT investment. While we prefer a different methodological specification, we cannot say much a priori about the quantitative dimension in which this difference affects estimation results.

In the face of competing methodological options, we opt for estimating the production function from a systems approach (the system of equation comprising the production function itself and the demand equations for two of three factors of production, the third equation being dropped because of collinearity).

Gregory, Salomons and Zierahn (2016): Racing With or Against the Machine? Evidence from Europe

Research Design: The abstract describes the aim and research design of the paper as follows: „This paper is the first to estimate the labour demand effects of routine-replacing technological change (RRTC) for Europe as a whole and at the level of 238 European regions. We develop and estimate a task framework of regional labour demand in tradable and non-tradable industries (…) and distinguish the main channels through which technological change affects labour demand. These channels include the direct substitution of capital for labour in task production, but also the compensating effects operating through product demand and local demand spillovers."

Database: The study uses data for 27 European countries from the European Labour Force Survey including regional information, which is available for all but the smallest countries. Employment is observed at the sectoral and occupational level. Sectors are classified into tradables and non-tradables. The occupations are matched with an index of routine task intensity. Data on output and industry marginal cost are obtained from the OECD STAN Database. The data is regionalised using employment shares as weights.

Methodology: The study is situated within the large body of research that observes the substitution of routine labour tasks by ICT. Based on empirical observation, it introduces the assumption that the tradable sector is more ICT intensive than the non-tradable sector. The simplified assumption is that only the tradable sector uses technological capital. On the labour supply side, the study assumes rigid wages and thus perfectly elastic labour supply.

Digitisation is here reflected in the declining relative cost of technological capital, which leads to a replacement of some of the routine working tasks by technological capital. Consumer demand for tradable goods and non-tradable goods is the second modelling element. It reflects increasing demand for tradable goods when the cost of technological capital declines. Besides a substitution and a price effect, the model exhibits what is called a product demand multiplier effect. Declining user cost leads to higher production in the local tradable sector and thus to higher local income. This is partly spent on local non-tradable goods, creating additional product and labour demand. This effect is only unambiguously positive when firm owners are also spending their profits locally. Because task-specific production cost is not observed, the relative decline in the cost of routine tasks is captured by a time trend. Labour demand for the tradable sector and product demand equations are derived from this modelling and are estimated. Labour demand observed at the level of regions and occupations over time is estimated as a function of regional production of tradables, regional marginal cost and a time-dependent measure of relative cost of the task content of the occupation. A general time trend is also included. Product demand is estimated as a function of the regional marginal cost of producing tradables and market potential. An IV strategy is employed.

Results: As expected, a decline in the relative cost of routine tasks is, ceteris paribus, found to decrease employment. Substitution between tasks in a given region is estimated to be limited. The substitution between regional task bundles also turns out to be limited, although stronger than the former.

With regard to overall employment in the period 1999-2010, calibrating the model with the estimated parameters finds that net job creation of 11.6 million has taken place as a result of declining costs of routine tasks. It adds up from job substitution of 9.6 million, product demand effects through lower prices of 8.7 million jobs and product demand effects from higher income spent on non-tradables of 12.4 million jobs. The result is sizeable given that total employment grew by 23 million during this period. In this calculation, all non-wage income is assumed to be spent locally. The other extreme is to assume that all non-wage income is not spent within the framework of the model, which would mean it is spent outside Europe. In this case the labour demand effect from higher income reduces by nearly 10 million and net job creation falls to 1.9 million. The authors moreover find that the effects vary substantially across regions.

Lessons learnt: Since there are only a small number of papers that assess the employment effects of digitisation, this study is of interest for the development of our own approach even if it differs in some features (routinisation instead of digitisation, regional dimension).

It should be pointed out that digitisation is not directly measured in this approach; only routine content of jobs is measured. Although the country coverage also differs, it is interesting to compare the overall employment effect in this study to the effect we obtain.

A key message the authors convey is that fears regarding job losses may be overstated, but that there remains uncertainty about the extent and the regional distribution of job creation. Assessing effects on product demand is crucial for this finding, thus this study validates the importance of the approach taken in our own study.

Blien and Ludewig (2016). Technological Progress and (Un)employment Development.

Research design: This is a further paper that highlights the importance of price elasticity of product demand for the effect of technological progress on employment. It looks in particular at regional variations in industry composition and how this affects total changes in regional labour demand.

Database: Data from the German Federal Statistical Office and the German Federal Employment Agency are used. They cover the years 1970 to 2004 for around 50 industries, some of which are excluded from the analysis. Variables covered are nominal gross value added, real gross value added, the national consumer price index and employment (employees subject to the social insurance scheme) at the industry-region level.

Methodology: The paper first derives labour demand equations from both a simple macro and a standard micro model and uses them to discuss the employment effects of technical progress. It highlights that the resulting equations are almost identical. Additionally, the paper compares the cases of exogenous and endogenous wages. The labour demand equation estimate, which is derived from the theoretical considerations, is a function of output quantity, national income and a set of control variables, which includes wage growth and some regional controls. The study applies an IV estimation technique.

Results: The study produces estimates of price and income elasticities of product demand for more than thirty German industries. These exhibit fairly high variation compared to those obtained by OECD (2016), which may result from a different level of aggregation and different modelling.

Lessons learnt: Since not many studies explicitly relate employment effects of technological progress to product demand, it is helpful to look at the modelling in this paper, although the paper does not consider ICT capital deepening. The paper also argues that it is useful to apply the estimation of Marshallian type demand functions to aggregate demand at the industry level, even if the method was originally developed for analysing consumer demand and not for intermediate demand. Unlike in OECD (2016), the authors do not impose the additional conditions of an Almost Ideal Demand System.

Further studies

Applied sectoral productivity and labour demand analysis can become rather complex given the interdependencies in an economy. There is a trade-off between simple and complex models. Simple models are easier to grasp in their functioning in each case of parameter constellations, but may omit important mechanisms present in reality. More complex models have the potential to better capture reality, but they also are more difficult to understand in their internal functioning and take more time to develop. Given the timing of the study and the lack of suitable models for intersectoral effects of ICT investment, we opt for a simple strategy. The advantages and drawbacks of this approach should still be clearly highlighted. William Nordhaus (2008), an eminent American scholar, took a similar approach in his paper on the hypothesis of “Baumol’s disease”. The only major difference between his paper and ours is that he looked at differential TFP growth rates across sectors and not at ICT investment. Nordhaus also combines productivity estimations with estimations of product demand equations based on an almost ideal demand system. He makes the following choices that are also relevant to our study:

- using value added, not gross output, as a output measure both for the analysis of productivity and product demand
- using a simplified equation compared to the AIDS system, which greatly reduces the number of parameters
- only taking demand for domestic production into account, which is more misleading for highly tradable sectors such as manufacturing and agriculture than for others assuming that pricing is at a mark-up over cost.

After the main empirical analysis of the present project had already been completed, we became aware of a further paper by Autor and Salomons (2017), which estimates employment effects of technological change at the sectoral level. It defines technological change as labour productivity growth in general, while our study is only focused on the part of labour productivity growth that can be attributed to digitisation. A main result of the paper is that within industry-effects of technological change on employment are negative while cross-industry effects can be positive. Summing up both effects, the authors find moderate positive employment effects of technological change at the aggregate level. It is possible that the empirical setting of the present study could also be extended to incorporate cross-industry effects in a more precise way. However, the shorter time span of our data may limit the possibility to introduce additional parameters.

3.3. Methods of data collection

We use a two-step approach in the empirical analysis. In a first step, we estimate how digitisation affects sectoral productivity and estimate how demand for sectoral output reacts to changes in sectoral output prices. In other words, we estimate a production and a demand function for each sector, where the production function takes ICT and non-ICT capital into account separately. Having derived substitution, output and price elasticities and other technology parameters, in a second step, we simulate consequences of digitisation in sectors for value-added prices, volumes and employment using the two functions obtained in a first step. The necessary data for doing so include, among others, value added, employment quantities and wages, (ICT) capital inputs and prices.

For the analysis of product demand it might have been preferable to use gross output instead of value added data. But suitable price indices are not available with the coverage required for this project.

Data for estimation

For the national accounts variables and the level of digitisation by industry, we primarily rely on the EU KLEMS November 2009 Release. The EU KLEMS database is freely available on the web (http://www.euklems.net). Data for Japan are taken from the EU KLEMS March 2008 Release. As data for China are not available in EU KLEMS, we primarily use data from the WIOD Socio Economic Accounts July 2014 Release. The WIOD Socio Economic Accounts do not provide separate information on ICT and Non-ICT capital. We therefore use additional information from the Conference Board Total Economy database (TED) for this country[1]. Both data sets are available on the web (http://www.wiod.org; https://www.conference-board.org/data/economydatabase/).

The year 2007 is in our view a suitable end period for the econometric estimation, because the financial crisis of 2007/08 makes it difficult to identify parameters in the years that follow. The observed time period since economic recovery is still too short to identify substantial changes in parameters after 2007. The econometric estimation is based on NACE rev. 1.1/ISIC rev. 3.1 data.

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[1] As a first step, we compare the total economy shares of ICT capital compensation in total capital compensation of China (from TED) with the shares of other countries for which data are available in EU KLEMS. Italy turns out to be very similar. We therefore use, in a second step, the share of ICT capital stock and ICT capital compensation of Italy to split up the total capital stock and total capital compensation (by industry) of China that is available in the WIOD Socio Economic Accounts.

Data for projection

While data for the first step (estimation) need to be obtained from empirical observations or close approximations to these, data for the second step can include predictions for periods where actual data are missing (e.g. such as for future periods). We base the data for the second step on empirical observations up to the year 2014.

For the projection, the most important empirical ingredients we need are value added, employment and ICT capital services and other capital services at the sectoral level. The other variables relevant for the final analysis can be simulated from the production function and the demand function estimated previously.

For the projection step, we rely on NACE rev. 2/ISIC 4 based data. For 13 of our proposed sectors (Agriculture, Forestry and Fishing; Chemicals and Chemical Products; Electrical and Optical Equipment; Machinery and Equipment; Transport Equipment; Electricity, Gas and Water Supply; Construction; Wholesale and Retail Trade; Transportation and Storage; Accommodation and Food Service Activities; Financial and Insurance Activities; Education; Health and Social Work), the differences between NACE rev. 1.1 and NACE rev. 2 are negligible. The only substantial difference occurs for NACE rev. 2 industry J (Information and Communication). For projection, the elasticities and other parameters for this industry are based on the NACE rev. 1.1 industries 64.[2]

The main data source is the updated EU KLEMS database. A first version for ten European countries based on SNA 2008 and NACE rev. 2/ISIC rev. 4 was released in December 2016. This so-called "statistical module" of EU KLEMS currently has some drawbacks. The dataset provides neither harmonised capital stocks nor separate data on ICT and non-ICT capital services. It is therefore not directly comparable to the "analytical modules" in previous EU KLEMS releases that we had hoped to be updated in the current version. An analytical module with harmonised capital measures, a broader set of countries (US and probably Japan) and separate data on ICT and non-ICT capital services is expected to be available in summer 2017 as a result of a project funded by EC DG ECFIN, which is carried out by The Conference Board. We therefore calculate ICT and non-ICT capital services on our own, based on the capital investment data of EU KLEMS 2016.

For the countries not included in the EU KLEMS Release 2016 (USA, China and Japan), we use data from the OECD national accounts (USA), a combination of the EU KLEMS Release 2012 and the OECD national accounts (Japan) and WIOD NACE1 based data for China (see Table 3 for details).

We also calculate industry-level profits (mark-ups). They are defined as:

$$profits = \sum_k (Ip_k * IRR * K_k) - \ (Ip_k * ERR * K_k)$$

With Ip_k the investment price index of asset *k,* IRR the internal rate of return, K_k the real capital stock of asset *k,* and ERR the external rate of return. The external rate of return is based on long-term interest rates for Government Securities/Government Bonds from the IMF International Financial Statistics (IFS).

[2] Previously, we suggested the use of weighted averages of 64 (Post and Telecommunications) and 71t74 (Renting of Machinery and Equipment and other business activities). Industry 71t74 includes industry 72 (Computer and related activities – our industry of interest). As 72 is only a minor part of 71t74, it is sensible to only use 64 Post and Telecommunications. See Table 1for details.

The forecasts for the years 2015-2021 are kept in line with the total economy GDP growth forecast from the IMF's World Economic Outlook Database April 2017. We assume that the ratios of industry level factor inputs (hours worked, ICT capital services and non-ICT capital services) to country level GDP continue to grow at the same rate as during the period 2000-2014. For instance, hours worked in 2015 (L) is therefore calculated as follows:

$$L_{i,2015} = L_{i,2014} * \left(\frac{L_{i,2014}}{L_{i,2000}}\right)^{\frac{1}{14}} * \frac{GDP_{2015}}{GDP_{2014}} * \left(\frac{GDP_{2014}}{GDP_{2000}}\right)^{-\frac{1}{14}}$$

Country and Industry Coverage

The final dataset provides results for the following 12 countries (sorted according to GDP in current US$): the United States, China, Japan, Germany, the United Kingdom, France, Italy, Spain, Netherlands, Sweden, Austria and Finland. The 14 economic sectors are based on the NACE rev. 2/ISIC 4 industry classifications and cover the most important industries from the manufacturing and services sectors as described in Table 1.

Table 2 describes the raw data sources for the data set that is used for estimation (NACE rev. 1.1). The comprehensive final NACE rev. 1.1 data set is already available for all countries for the years 1995-2007. Table 3 describes the raw data sources used for the final data set production, including the projection (NACE rev. 2). Data are missing for the chemical sector (NACE 2 sector 20-21) in Sweden and for the Transport Equipment sector in the UK (NACE 2 sector 29-30).

The **data coverage** follows from the previous data description. We cover:

- 12 Countries (sorted according to GDP in current US$): the United States, China, Japan, Germany, the United Kingdom, France, Italy, Spain, Netherlands, Sweden, Austria and Finland.[3]
- The period from 2000[4] to 2021, for which we usually have observational data available for the time from 2000 up to 2014 and are able to forecast data until 2021.
- 14 NACE rev. 2 industries:

[4] For some countries, NACE rev. 2 data would also be available for years before 2000. We nevertheless prefer to have a common starting year.

Table 1: Industry coverage

#	NACE 2	NACE 2 DESCRIPTION (EU KLEMS)	NACE 1.1	NACE 1.1 DESCRIPTION (EU KLEMS)
1	A	Agriculture, Forestry and Fishing	AtB	Agriculture, Hunting, Forestry and Fishing
2	20-21	Chemicals and Chemical Products	24	Chemicals and Chemical Products
3	26-27	Electrical and Optical Equipment	30t33	Electrical and Optical Equipment
4	28	Machinery and Equipment N.E.C.	29	Machinery, Nec
5	29-30	Transport Equipment	34t35	Transport Equipment
6	D-E	Electricity, Gas and Water Supply	E	Electricity, Gas and Water Supply
7	F	Construction	F	Construction
8	G	Wholesale and Retail Trade; Repair Of Motor ...	G	Wholesale and Retail Trade
9	H	Transportation and Storage	60t63	Transport and Storage
10	I	Accommodation and Food Service Activities	H	Hotels and Restaurants
11	J	Information and Communication	64	Post and Telecommunications (1)
12	K	Financial and Insurance Activities	J	Financial Intermediation
13	P	Education	M	Education
14	Q	Health and Social Work	N	Health and Social Work
			(1) does not include industry 72 Computer and Related Activities	

The countries covered include nine of the EU15 countries. EU15 countries not included are Belgium, Denmark, Ireland, Greece, Luxemburg and Portugal. In 2014, these countries accounted for about ten percent of the total GDP in the EU15 (Eurostat). Data on value added and employment at the sectoral level are available for these countries from Eurostat. We add employment effects for the EU15 at the sectoral level, extrapolating ICT investment and its impact to missing countries. It must be emphasized, however, than we are unable to account for any deviation of the ICT investment pattern and its impact on productivity and employment in the missing countries.

3.4. Methods of modelling and econometric estimation

The starting consideration is that higher ICT investment is mainly driven by a declining ICT user cost. The rapid decline of the ICT user cost has been famously termed Moore's law, according to which the cost of computing falls by half every two years. Although the empirical validity may be questioned depending on precisely which cost elements one looks at, and although there seem to be recent signs of this decline slowing down, the cost of computing has been declining massively over the last five decades.

Based on the minimisation of a neoclassical cost function (of which we do not need to know the precise form at this point), the effect of lower ICT user cost on labour demand can be analysed. The total effect of a decline in ICT user cost uc_{IT} on labour input H under cost minimisation is summarised in the following equation, which also lies at the heart of the sectoral analysis undertaken by OECD (2016):

$$\frac{\partial ln\, L}{\partial ln\, uc_{IT}} = c_{IT}\sigma_{H,IT} - \varepsilon(1 - s_M)c_{IT} + \eta(-s_M c_{IT})$$

In this equation, c_{IT} is the cost share of ICT capital in total cost, $\sigma_{H,IT}$ the Allen partial elasticity of substitution between labour and ICT capital, ε the elasticity of final demand to prices, s_M the share of monopolistic rents in total value added and η elasticity of final demand to income. The equation is evaluated at the sectoral level.

We have to emphasize that we measure digitisation here as increases in ICT capital services, which result from higher ICT investment. Nowadays digitisation takes a number of forms which may not be directly measured by ICT investment. For example, a machine with digital functionalities may still be counted as non-ICT capital in the data. Digital input into the production of the machine probably is measured in this case, but the machine is not counted as digital investment in the sector where it is used. To date, measures to comprehensively account for these aspects in sectoral analysis are lacking. Thus we follow the majority of the research undertaken to date and do not attempt to quantify those. In addition to digitisation being embodied in capital goods classified as non-digital, product and process innovation based on digitisation may affect total factor productivity. Total factor productivity, may, however, also reflect many other influences, such as unmeasured intangibles, non-digital innovation, quality of institutions, non-constant returns to scale and measurement error. In this study, we only include TFP increases in the ICT-producing sectors.

Diagram 1 illustrates the relationship between ICT diffusion and labour demand expressed in the key equation of the study. This relationship depends mainly on two opposing forces: a substitution effect, which results from increasing cost of labour relative to ICT, and a demand effect, which increases output as a result of declining total cost. More precisely, it is assumed that the decline in ICT user cost changes the input mix. The strength of this effect depends on the substitutability of labour by ICT assets which we measure by the Allen elasticity of substitution between labour and ICT ($\sigma_{H,IT}$). The stronger the substitutability, the more employment can be saved when ICT input rises as a result of declining user cost. Which share of employment is actually replaced by ICT depends in addition on the share of ICT in total cost (c_{IT}). If this share is already large, the effect of a further user cost decline on employment will also be larger ceteris paribus. The product of both terms, $c_{IT}\sigma_{H,IT}$, represents the cross-price elasticity of labour demand with respect to ICT user cost. From the literature review we have seen that the aggregate cost share amounts to around five percent. This still relatively low share is responsible for predicted employment effects of ICT that are much lower than one could expect from the public discussion.

On the other hand, the decline in user cost and the substitution of labour lead to higher labour productivity (Y/L) and lower unit costs of production. This reduction in unit cost has two effects: first, it allows reducing output prices and secondly, assuming some market power of producers, it allows for higher profits (mark-ups), which result in higher disposable incomes. Both effects increase product demand and thus result in higher output. The strength of the latter two effects depends on price (ε) and income (η) elasticities of demand, i.e. they depend on how strongly sectoral product demand reacts to changing product prices and income levels.

Together, the effect of ICT on labour productivity (which is equal to a reduction in labour demand per unit of output) and the effect on output (through changing prices and income) then determine the overall effect on labour demand.

Given what we know a priori, there is some reason to expect an overall neutral effect. Based on previous research, we expect an elasticity of substitution between labour and ICT that is higher than one but not drastically higher. In addition, very high elasticities are difficult to discriminate given the difficulties in estimating production functions. On the demand side, aggregate effects of lower prices and higher nominal income on real demand are one-to-one, since both directly raise real income (see also OECD, 2016). Sectoral elasticities may differ, but to the extent that they do not differ drastically, substitution and demand elasticities would overall have a tendency to compensate to a small effect. Large positive and negative employment effects from this approach would emerge in cases where the output elasticity of ICT is large and where the substitution elasticity diverges much from the demand elasticities in magnitude.

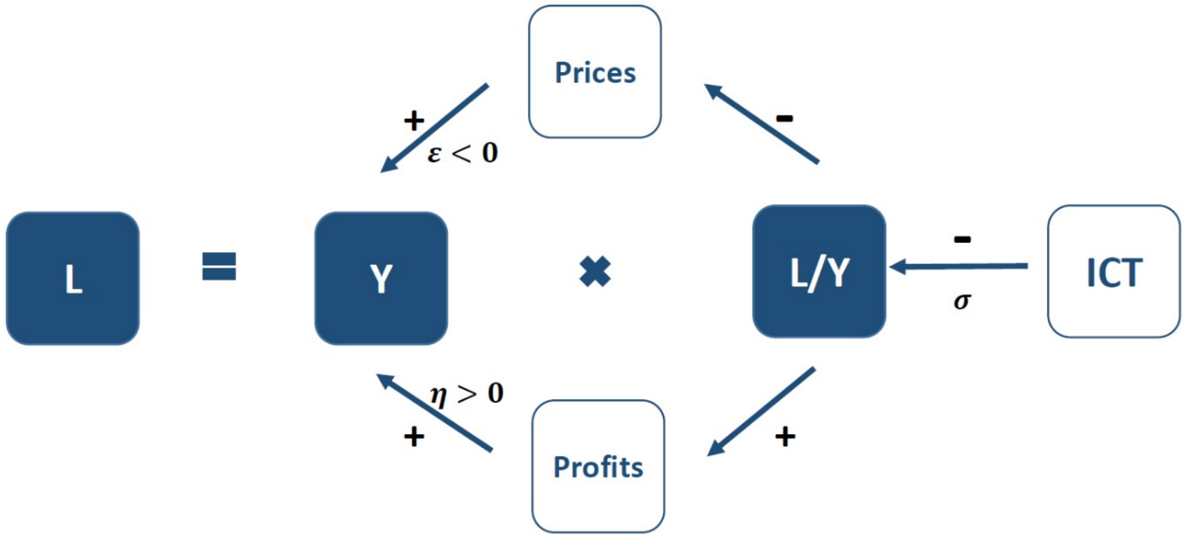


Diagram 1: This diagram illustrates the interrelation between the main variables and parameters in the model.

Model for the impact on productivity by sector

Econometric model: Based on the review of the relevant literature, an econometric model is specified to obtain parameter estimates that allow us to model the productivity impact by sector. We estimate a translog production function jointly with its factor cost share equations. This function is estimated for each sector separately. To model changes in total factor productivity (TFP) and to control for unobserved country-specific heterogeneity within industries, we include country dummies and country-specific constant TFP growth rates (i.e. one time trend per country and industry).

In levels of inputs and output, the translog production function which we estimate for a particular sector (observed in different periods *t* and countries *i*) is written as follows:

$$\ln Y_{it} = \alpha_i + \mu_i t + \beta_{ICT} \ln ICT_{it} + \beta_{NICT} \ln NICT_{it} + \beta_L \ln L_{it}$$

$$+0.5\beta_{ICT^2} (\ln ICT_{it})^2 + 0.5\beta_{NICT^2} (\ln NICT_{it})^2 + 0.5\beta_{L^2} (\ln L_{it})^2$$

$$+\beta_{ICT,NICT} \ln ICT_{it} \ln NICT_{it} + \beta_{NICT,L} \ln NICT_{it} \ln L_{it} + \beta_{L,ICT} \ln L_{it} \ln ICT_{it} +$$

The sectoral subscript is omitted. We estimate the function jointly with the factor cost share equations (for ICT- and non-ICT capital) that can be derived from the production function under the common assumption of cost minimisation, which implies that marginal products equal factor prices:

$$c_{it}^{ICT} = \frac{P_{ICT} ICT}{Y} = \frac{\frac{\partial Y}{\partial ICT} ICT}{Y} = \frac{\partial \ln Y}{\partial \ln ICT} = \beta_{ICT} + \beta_{ICT^2} \ln ICT_{it} + \beta_{ICT,NICT} \ln NICT_{it} + \beta_{L,ICT} \ln L_{it} + u_{2it}$$

$$c_{it}^{NICT} = \frac{P_{NICT} NICT}{Y} = \frac{\frac{\partial Y}{\partial NICT} NICT}{Y} = \\ = \beta_{NICT} + \beta_{NICT^2} \ln NICT_{it} + \beta_{ICT,NICT} \ln ICT_{it} + \beta_{L,NICT} \ln L_{it} + + u_{3it}$$

In addition, to ensure symmetry and constant returns to scale, the following constraints are imposed:

$$\beta_{jk} = \beta_{kj}$$

$$\sum_{k \in \{ICT,NICT,L\}} \beta_k = 1$$

$$\sum_{j,k \in \{ICT,NICT,L\}} \beta_{jk} = 0$$

In this specification, *Y* is output (measured by real value added), *ICT* is ICT capital input (measured by ICT capital services), *NICT* is non-ICT capital input (measured by non-ICT capital services) and *L* is labour input (measured by hours worked).[5] The subscript *i* represents countries and *t* equals a given a year.
To estimate the production function jointly with its factor demand equations, which together constitute a system of linear equations, we apply the seemingly unrelated regression estimation (SURE) method (Zellner, 1962).[6] It allows error terms to be correlated across equations and to impose cross equations restrictions that are necessary for the standard neoclassical properties of the production function to hold.[7]

Based on the estimated production function, we can then derive an expression for the output elasticity of ICT capital services, which illustrates how additional ICT use affects output and productivity:

$$\frac{\partial \ln Y}{\partial \ln ICT} = \beta_{ICT} + \beta_{ICT^2} \ln ICT_{it} + \beta_{ICT,NICT} \ln NICT_{it} + \beta_{L,ICT} \ln L_{it}$$

---

[5] Value added, value-added price indices and hours worked are directly taken from external data sources. In contrast, the growth rates of ICT capital services as well as non-ICT capital services have to be generated by us. They are calculated as the growth rates of the real net stocks of the single assets (information technology equipment, communication technology equipment and software for ICT) weighted by their factor shares in total ICT (non-ICT) capital compensation. The following equation illustrates this approach:

$$\Delta \ln K_t = \ln K_t - \ln K_{t-1} = \sum_l v_l \left(\ln S_{l,t} - \ln S_{l,t-1}\right),$$

where $\Delta \ln K$ equals the growth rate of either ICT or non-ICT capital services, $\ln S_{l,t}$ are the capital stocks of the individual assets that are aggregated and the l are weights equal to factor shares in total ICT (non-ICT) capital compensation.

[6] The SURE method essentially consists of a GLS estimator which takes into account potential cross-equation correlation of the errors which improves the efficiency of the estimates.
[7] For the estimation we exclude outliers with respect to output growth, ICT- and non-ICT capital compensation shares as well as capital prices. This reduced the number of observations for some sectors.

This elasticity can then be used to evaluate the contribution of ICT capital to labour productivity growth. Labour productivity is defined as value added divided by hours worked (Y_{ijt}/L_{ijt}), for the countries, sectors and years covered.

Based on the growth accounting approach, the contribution of growth in ICT capital services to labour productivity growth is computed in the following way:

$$CONICT = ((c_{it}^{ICT} + c_{it-1}^{ICT})/2) * (\Delta \ln ICT_{it} - \Delta \ln L_{it})$$

where Δ is the difference operator and cost shares are replaced by their values predicted by the model (not by their actual values as in standard growth accounting).

Projection: For the projection of effects for the period 2000 to 2021, we use the estimated parameters of the translog function at the sectoral level for the years 1995 to 2007 (using the NACE 1.1 data) and project increases in labour productivity using NACE 2 data.

Allen Elasticity of Substitution (AES):

Allen (1934) originally defined his partial elasticity of substitution, which measures the ease of substitution of one input for another, holding output and all other input quantities constant, in terms of a production function as:

$$AES_{L,ICT} = \frac{H_{L,ICT}}{|H|},$$

where $|H|$ is the determinant of the bordered Hessian matrix of the production function and $H_{L,ICT}$ is the co-factor associated with the $m,$nth element of the H.

Methodological comments: The estimation of the elasticity of substitution between labour and ICT requires a flexible production function, i.e. a production function which allows the substitution elasticities to be determined by the data. The most inflexible production function with regard to partial elasticities of substitution (i.e. elasticities of substitution between two factors in functions with three or more factors) is the Cobb-Douglas function, which restricts the partial elasticities to one. The trade-off between the flexibility of the function and ease of identification has been known for a long time. Flexible functions often exhibit either the problem that they do not globally satisfy the assumptions of neoclassical production theory, which are needed for our analysis, or that they are highly nonlinear. Since we want to directly estimate the input-output relation underlying the function, linearity of factor demand does not help in our case. With the estimation of a translog function, we have the advantages of flexibility and linearity in parameters, but the function is not globally a neoclassical production function. In the projection of effects, imputations for some ranges of the function outside of its neoclassical area had to be made. Also the translog function is not completely flexible, since it imposes certain patterns of change of the partial elasticities. Estimating partial elasticities of substitution from production functions is inherently difficult. This problem is not particular to the present project.

For the results of our analysis, it is important to know whether the elasticity of substitution between labour and ICT is different from one. We have undertaken a simple test of joint significance of the cross effects causing non-unitary elasticities which does not point to unitary elasticities of substitution. Further bootstrapping of results under different assumptions, however, leads to various results on standard errors. As a consequence, we have added in the Appendix a sensitivity analysis where all Allen elasticities are unity. For the sector Transport and Storage, regression results moreover proved extremely sensitive to dropping single countries. For this reason, we restrict the production function to Cobb-Douglas in this sector in the whole analysis.

Two open issues we were not able to tackle within this project are dynamic effects and endogeneity. Productivity and demand can be expected to react with a lag towards shocks from ICT. To capture such effects a dynamic specification which allows for a lagged adjustment would be worth studying in future research. In our case, because of the short time dimension (13 years), it was not possible to implement such a specification. Attempts to do so showed high instability of results. Similarly, endogeneity of inputs and outputs which might bias the results of the SURE estimation, might be a problem. However, using GMM-type estimators, a common approach which can help to resolve this issue, would have been problematic in our case given the low number of observations per sector. In addition, these estimators typically do not allow for cross-equation restrictions, which are essential to our model.

Model for the impact on prices, product demand and employment

In a first step, we estimate the price and income elasticity by a demand function. Real demand for the product of a sector *j* in a country *i* depends on the product price, on an index of all other product prices and on nominal income available in country *i*. We have chosen this form after experimenting with the more complex Almost Ideal Demand System (Deaton and Muellbauer, 1980), which yielded implausible positive price elasticities in three sectors, and with a simpler demand function based on Nordhaus (2008), which would have required the unsuitable assumption that all sectors are small compared to the total economy (see also Blien and Ludewig, 2016).

The demand equation for output of sector *j* in country *i* is the following:

$$\ln Y_{ijt} = \lambda_{ij} + \varepsilon_j \ln P_{ijt} + \theta_j \ln P'_{ijt} + \eta_j \ln YN_{it} + u_{ijt},$$

where Y_{ijt} is real value added in sector *j* and country *i* (of production sold both within the country and abroad), P_{ijt} is the corresponding price index, P'_{ijt} is an aggregate price index of all sectors included in the analysis minus the contribution of the index in sector *j* to that aggregate index. This is a summary measure to take into account cross-price effects. YN_{it} is the sum of nominal value added in the sectors analysed in country *i*. ε_j is the elasticity of demand for sectoral value added to sectoral prices, η_j is the elasticity of demand to income.

Summing up effects:

For evaluating the overall effect in the key equation, we plug in the elasticities of substitution and product demand from the production function and the demand function as well as the predicted ICT cost share from the production function. The share of monopolistic rents in value added is set equal to its empirical value. In order to compute the actual change in labour demand associated with changes in ICT capital services, we have to compute the change in user cost. In contrast to a number of other papers, we choose a measure of change in user cost that reflects the actual ICT investment that has taken place, thus eliminating ICT effects that match a user cost decline which has failed to lead to the amount of ICT investment that would have been predicted in the absence of any market frictions. The measure we are using is the change in ICT in user cost predicted by the model given the observed change in ICT capital services. It is obtained by evaluating the logarithm of the first derivative of the production function at the ICT levels in times *t* and *t-1* one and taking the difference:

$$\Delta \ln uc_{it}^{*} = (\beta_{ICT} + \beta_{ICT^2} - 1)\Delta \ln ICT_{it} + \beta_{ICT^2}\Delta (\ln ICT_{it})^2 + \beta_{ICT,NICT}\, \Delta \ln ICT_{it} \ln NICT_{it} + \beta_{L,ICT}\Delta \ln ICT_{it} \ln L_{it}.$$

The total employment effects of ICT are computed for both individual sectors and the aggregate of all sectors observed. Some of the intermediate results are not computed for the aggregate of all sectors and thus display missing values for the aggregate.

Methodological comments:

A large part of productivity growth is not directly attributable to investment within a production function framework but results from total factor productivity growth. We understand by total factor productivity growth the growth in output that is not explained by growth in inputs (weighted with the output elasticity of the production function). In our approach, TFP is captured by the time trends and the error terms of the production function. While attempts to relate TFP growth in all sectors to ICT investment have faced difficulties in obtaining robust results, a direct relation of TFP to ICT prevails in the ICT-producing sector itself. We thus follow Cardona et al. (2013) in including in our estimate of the labour market effects of digitisation the increase in labour demand resulting from an increase in TFP in the ICT-producing sectors. According to the NACE2 classification, these are 26-27 (Production of Electrical and Optical equipment) and J (Information and Communication). As Niebel and Saam (2016) discuss for Germany, sector 26-27 contains some non-ICT products, but their share is not large (around 10 percent for Germany).

The elasticity of labour demand with respect to a change in TFP in the ICT industries equals:

$$\frac{\partial \ln L}{\partial \ln TFP_{IT}} = -\varepsilon(1 - s_M) + \eta(-s_M)$$

It resembles the elasticity of labour demand with respect to ICT user cost, but does not contain a substitution effect and the income and price effects do not depend on the ICT capital compensation share in total factor compensation, the reason being that a change in TFP improves the productivity of all production factors and thus does not lead to substitution between factors. It also leads to a one-to-one cost reduction whereas a change in ICT user cost affects unit production costs depending on the share of ICT capital compensation in the input mix. What we ignore here is that TFP growth might in fact represent non-neutral technological change which affects relative factor demand. This would probably lower the TFP effect on employment. We also ignore TFP growth related to digitisation in sectors other than ICT, which in turn would add positive employment effects there. Compared to the analysis of growth in ICT capital services, there is little established evidence to model these effects and a more precise model must to be left to future research.

To compute the effect of an improvement in TFP of sectors 26_27 and J on labour demand we need to compute a measure of TFP changes. We do so by backing out TFP through the following formula:

$$\Delta \ln TFP_{it} = \Delta \ln Y_{it} - c_{itL}\Delta \ln L_{it} - c_{itICT}\Delta \ln ICT_{it} - c_{itNICT}\Delta \ln NICT_{it} \ ,$$

where the c_{it} are predicted factor cost shares taken from the production function estimation.

4. GRAPHICAL REPRESENTATION OF RESULTS

4.1. Evolution of value added and inputs

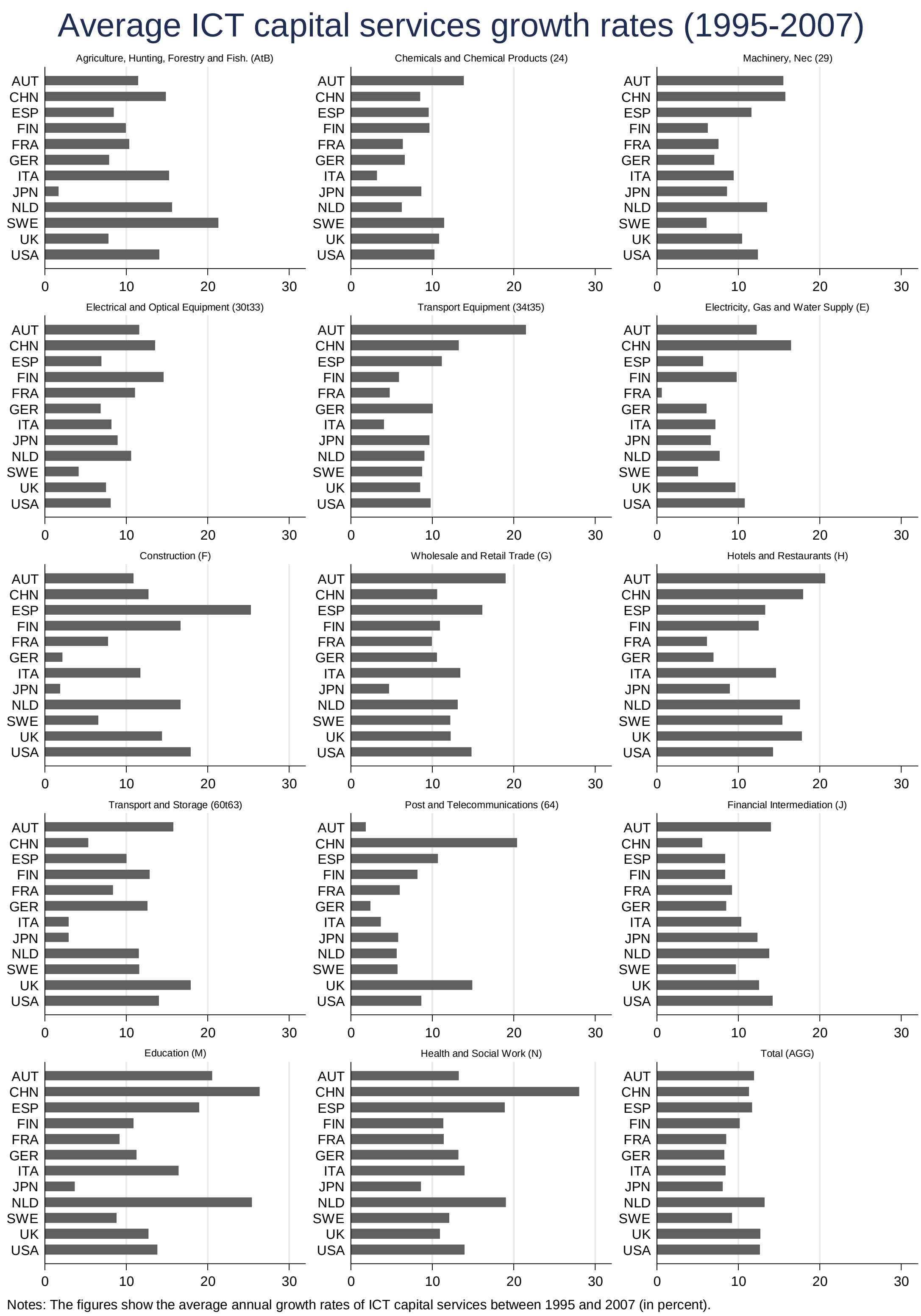


Figure 5: Average ICT capital services growth rates (1995-2007)

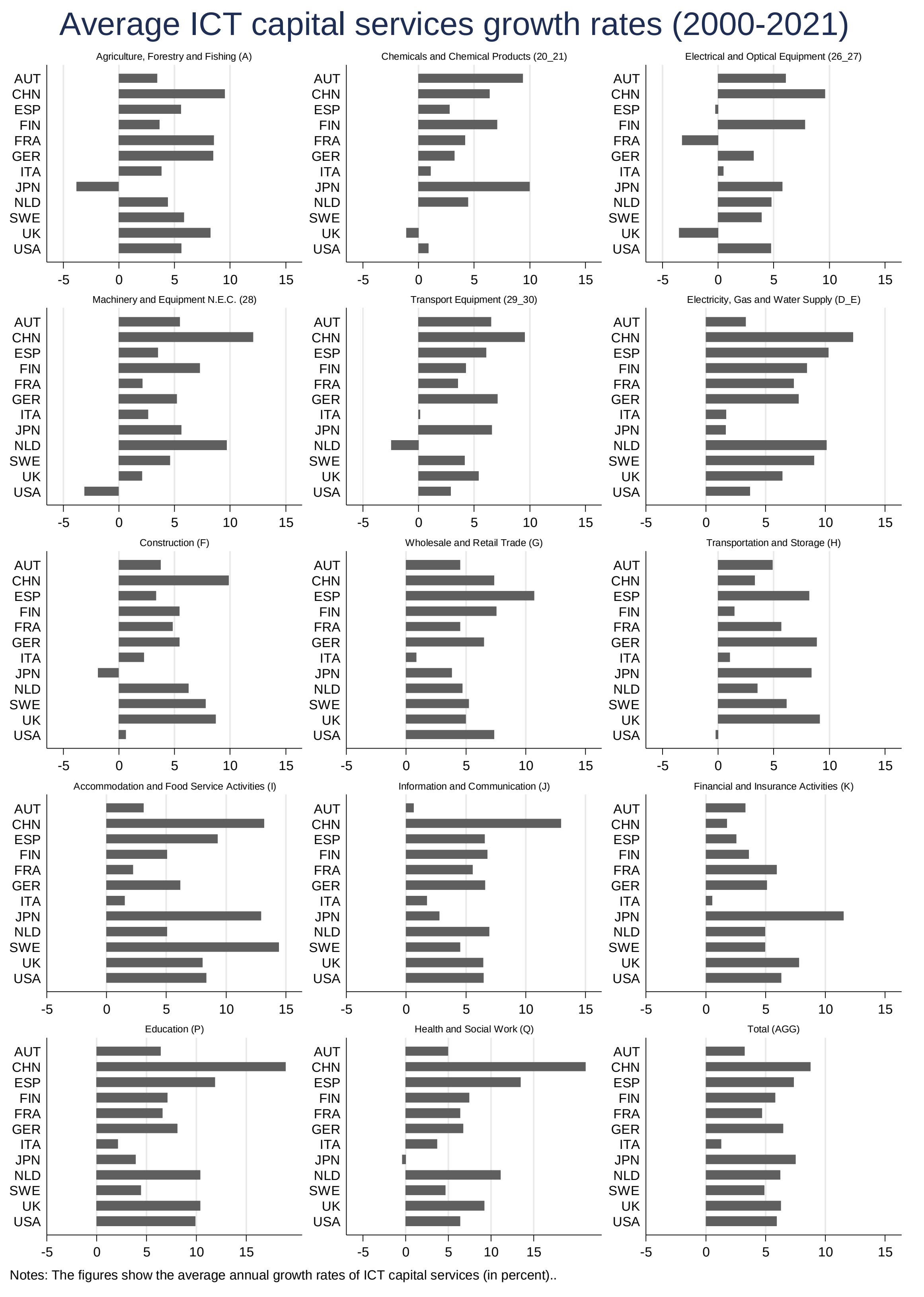


Figure 6: Average ICT capital services growth rates (2000-2021)

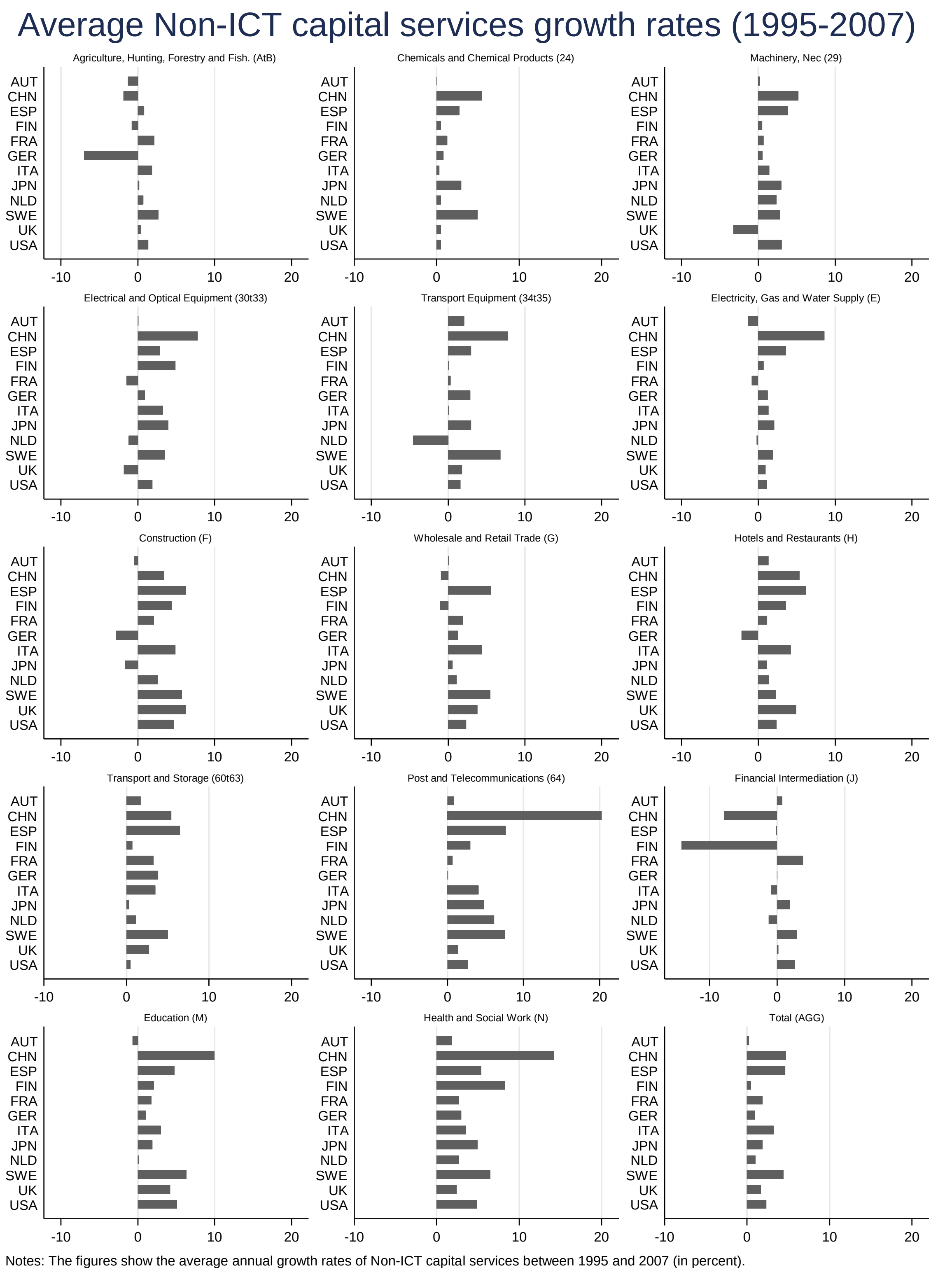


Figure 7: Average non-ICT capital services growth rates (1995-2007)

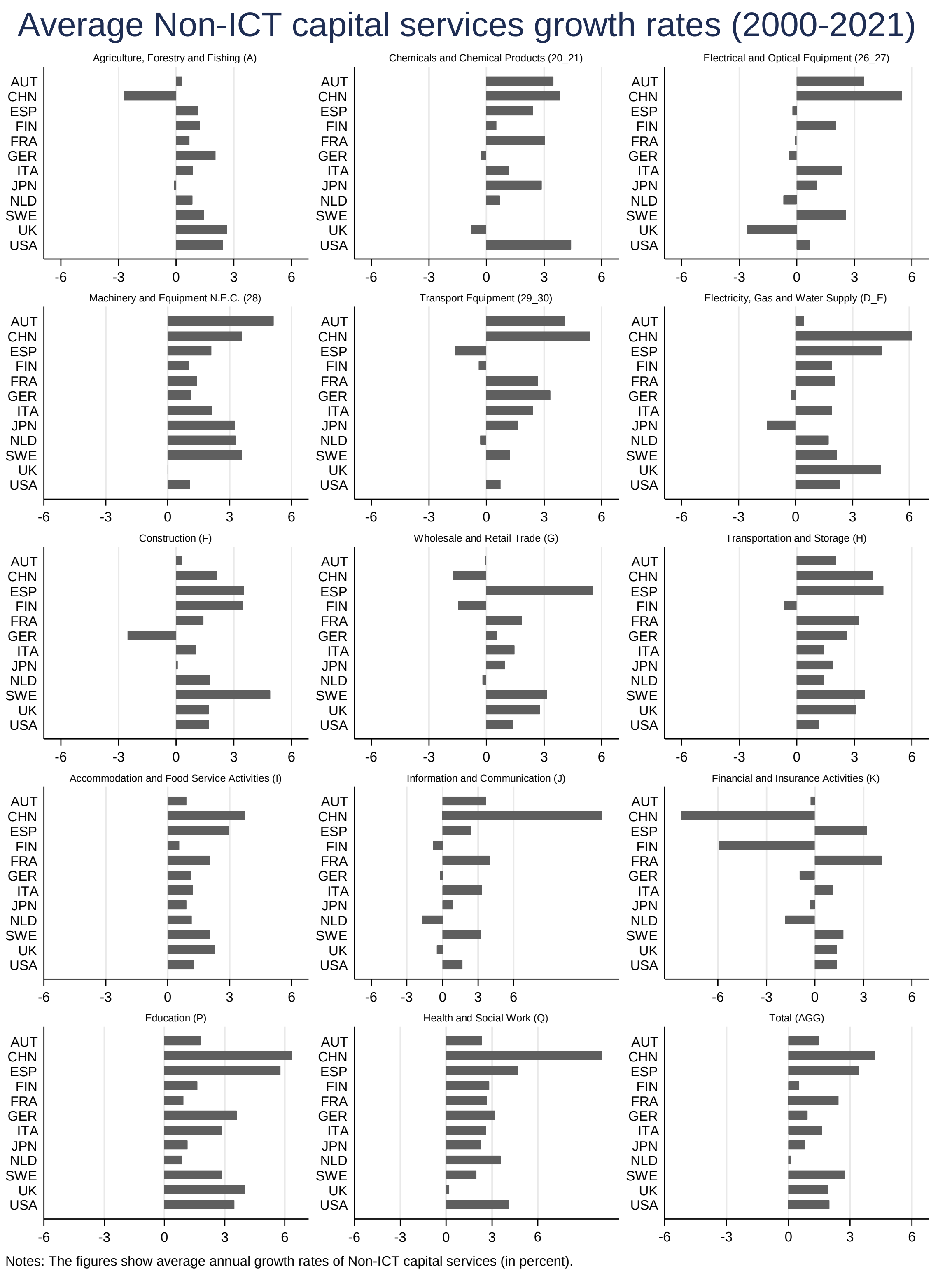


Figure 8: Average non-ICT capital services growth rates (2000-2021)

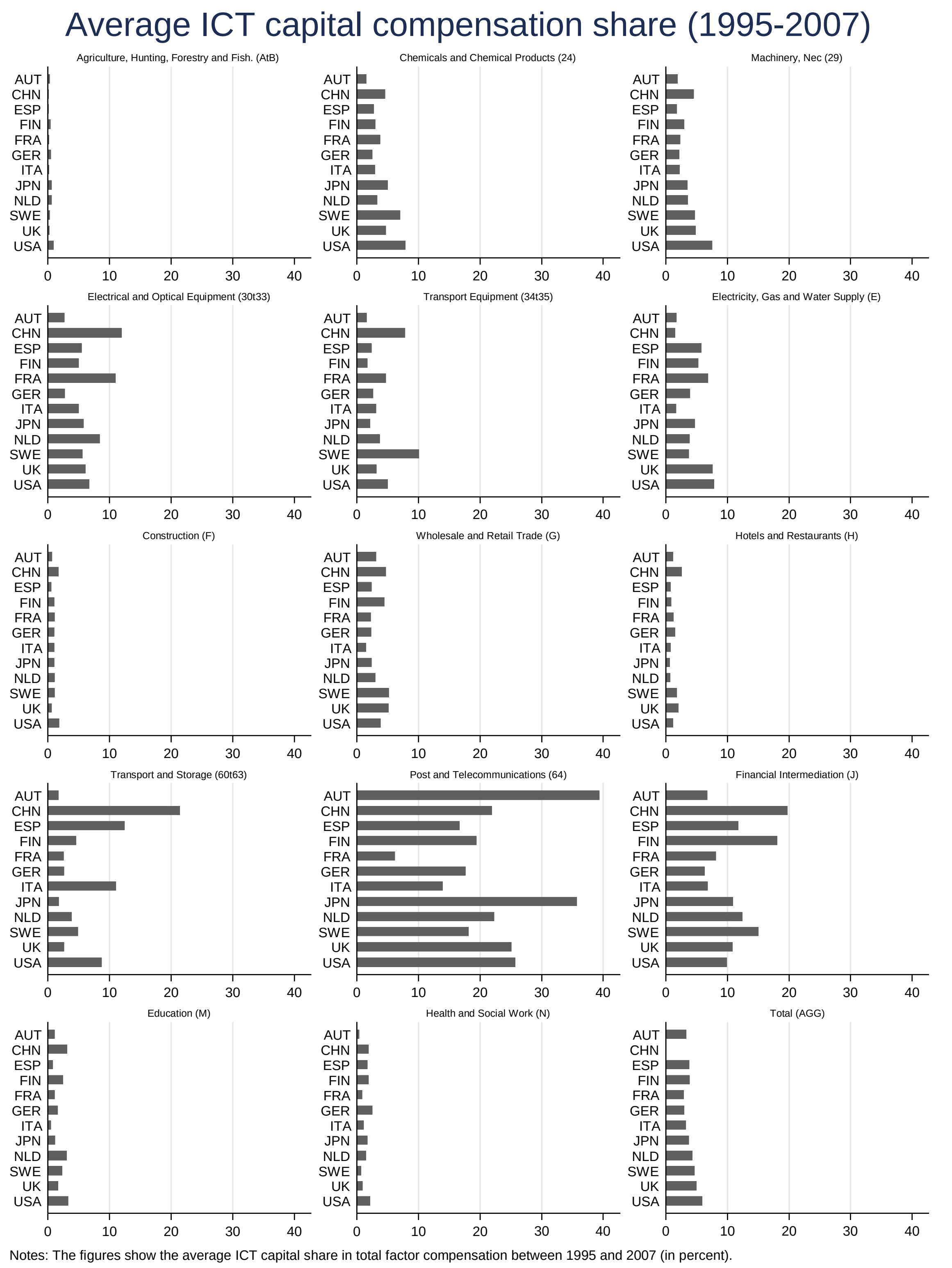


Figure 9: Average ICT capital compensation share (1995-2007)

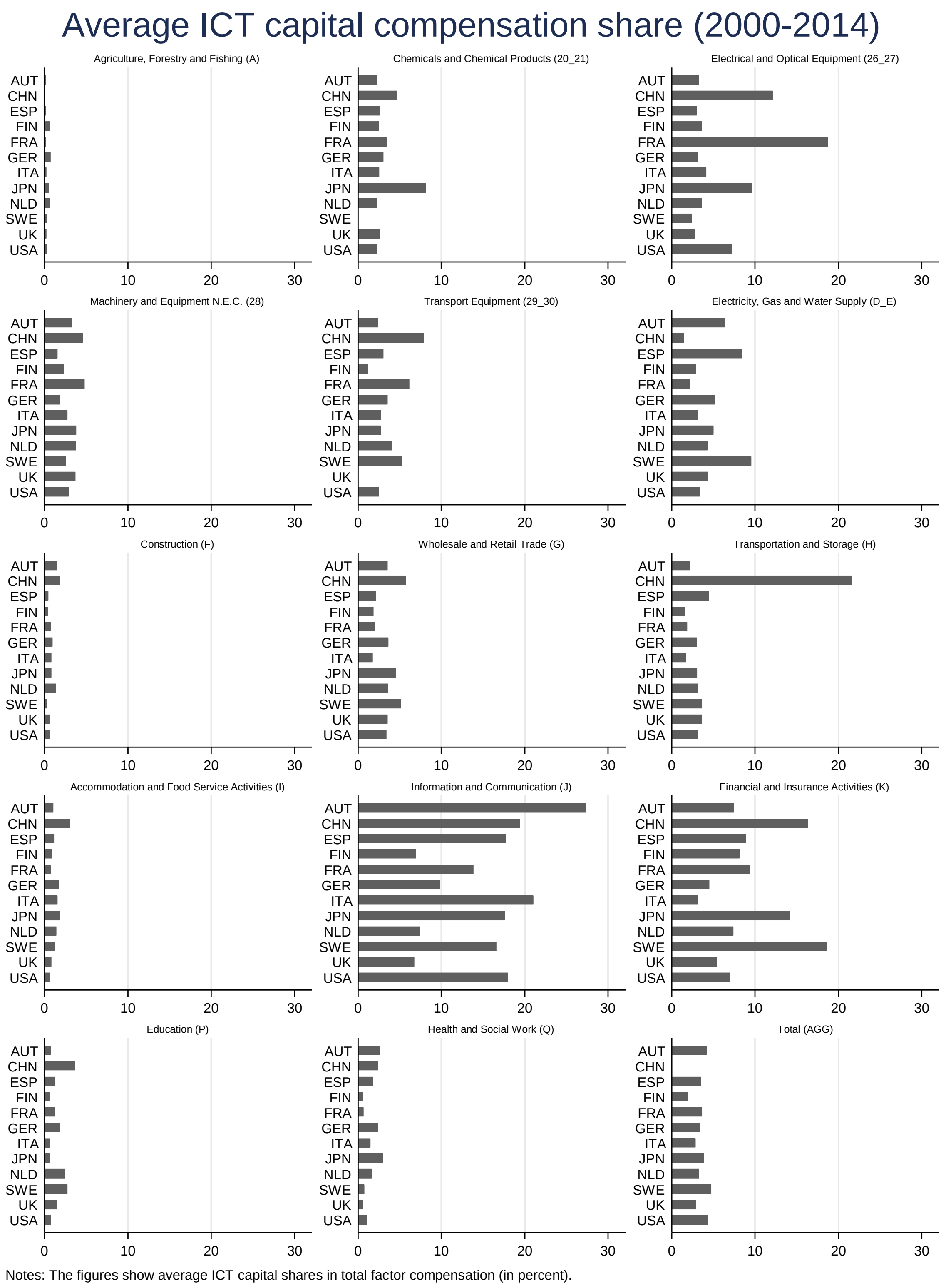


Figure 10: Average ICT capital compensation share (2000-2014)

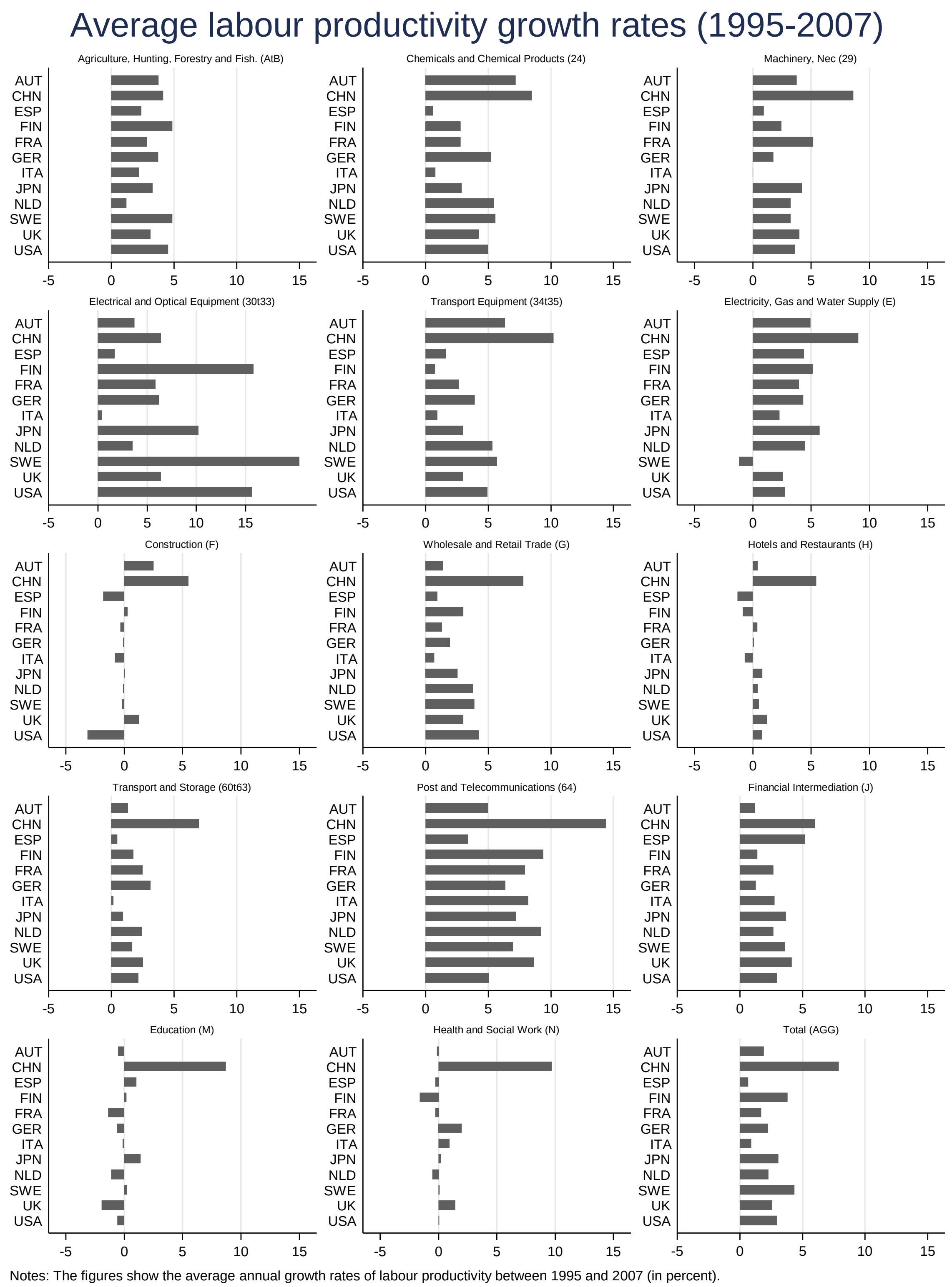


Figure 11: Average labour productivity growth rates (1995-2007)

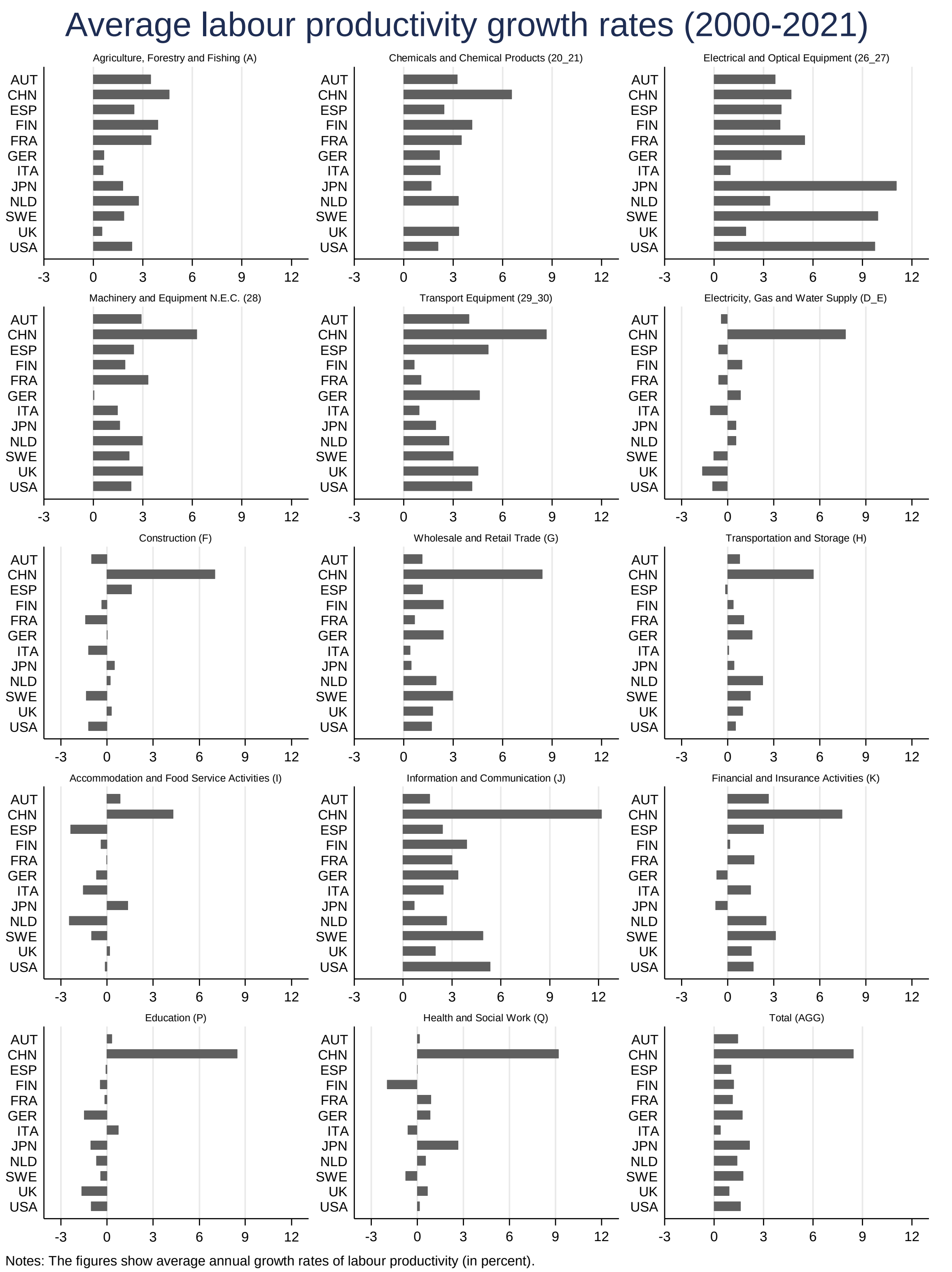


Figure 12: Average labour productivity growth rates (2000-2021)

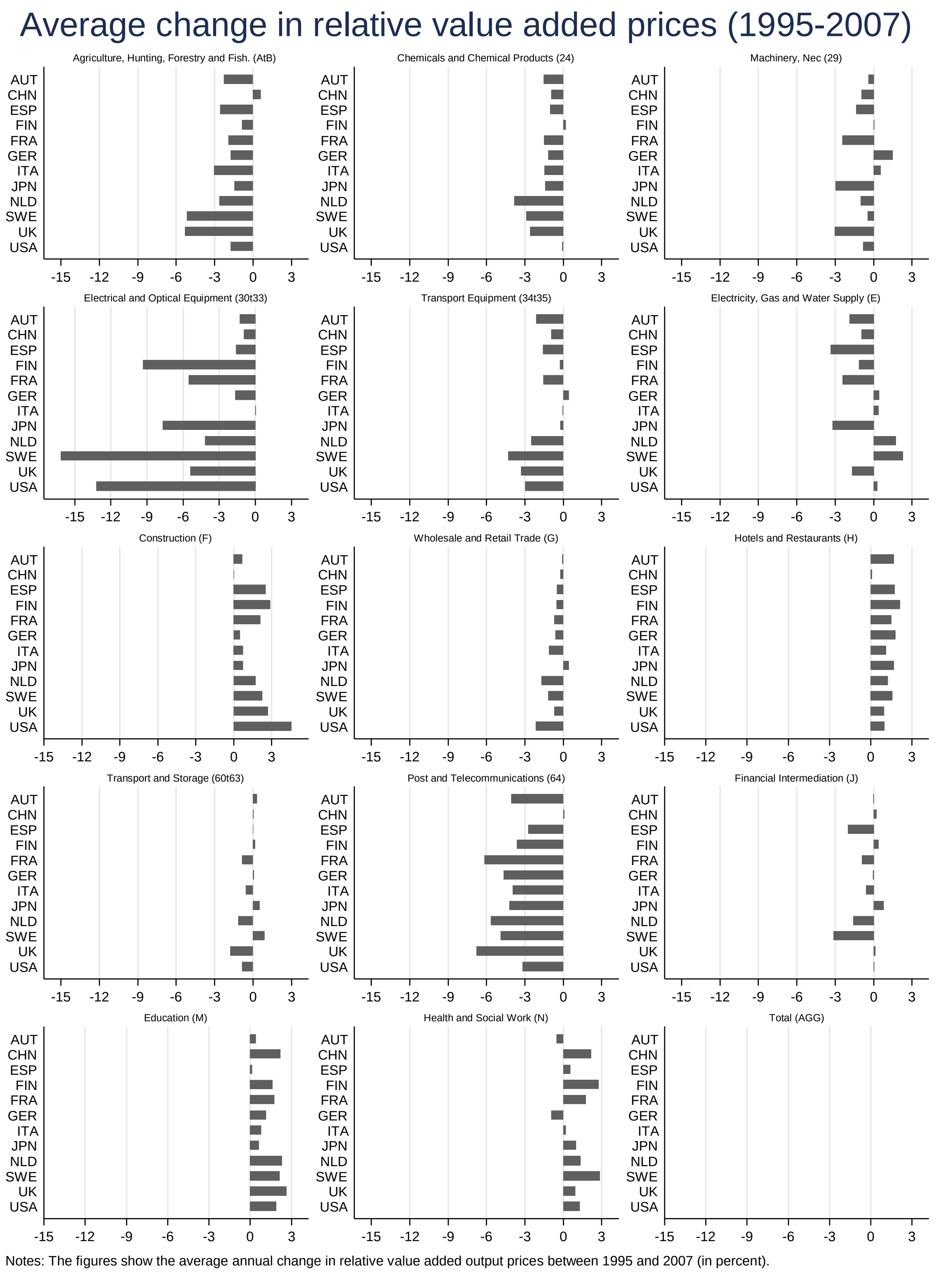


Figure 13: Average change in relative value-added prices (1995-2007)

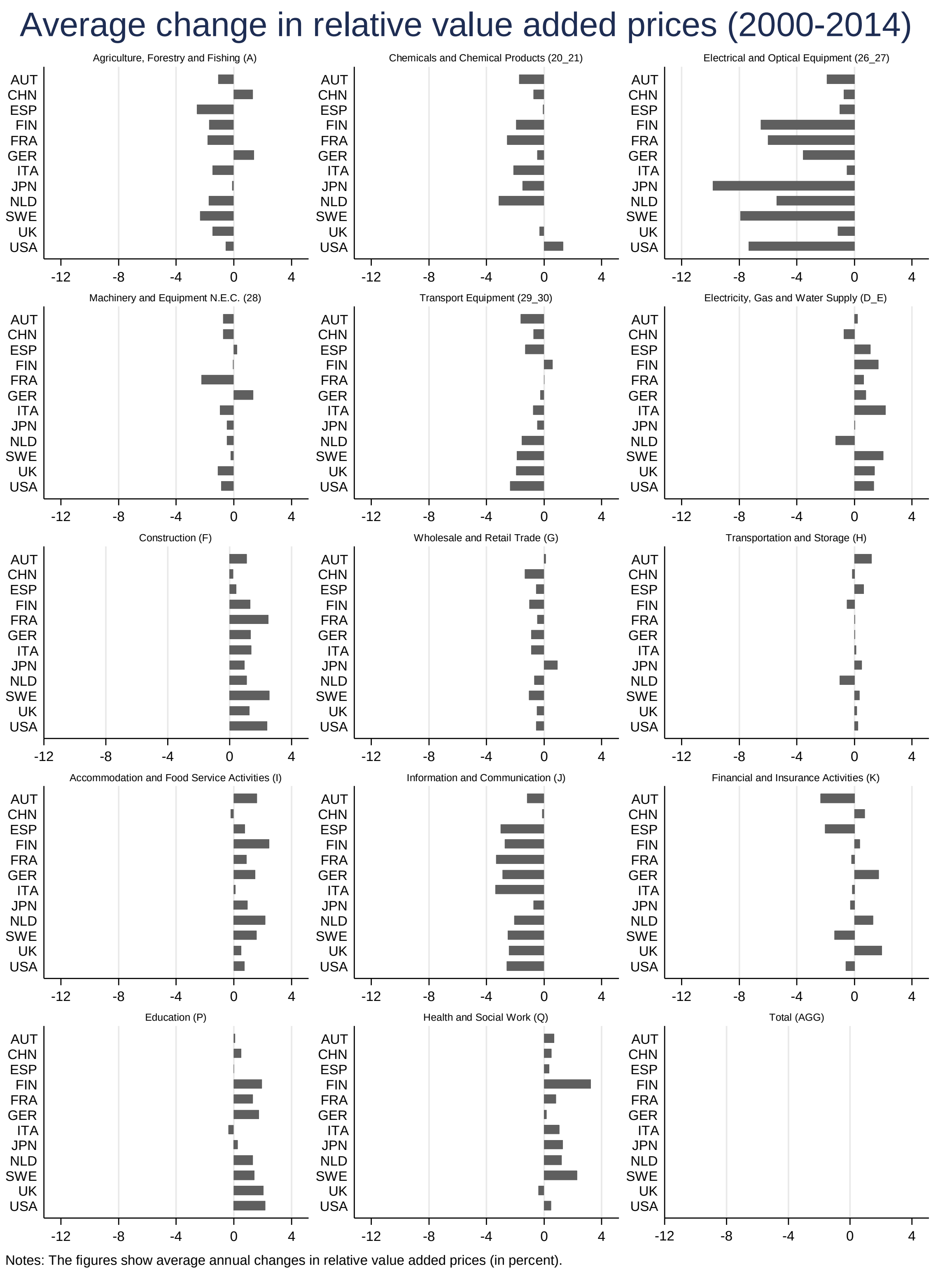


Figure 14: Average change in relative value-added prices (2000-2014)

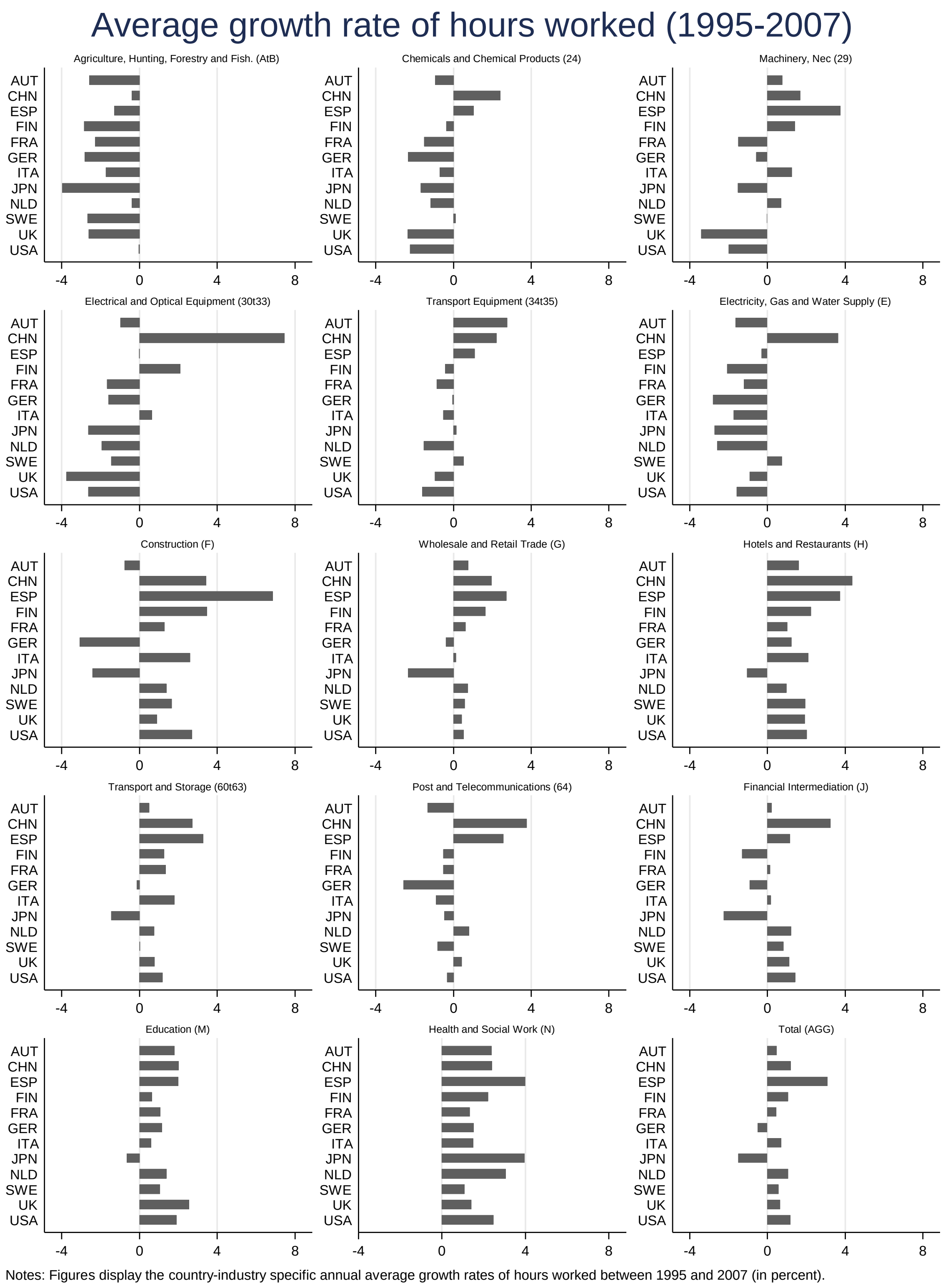
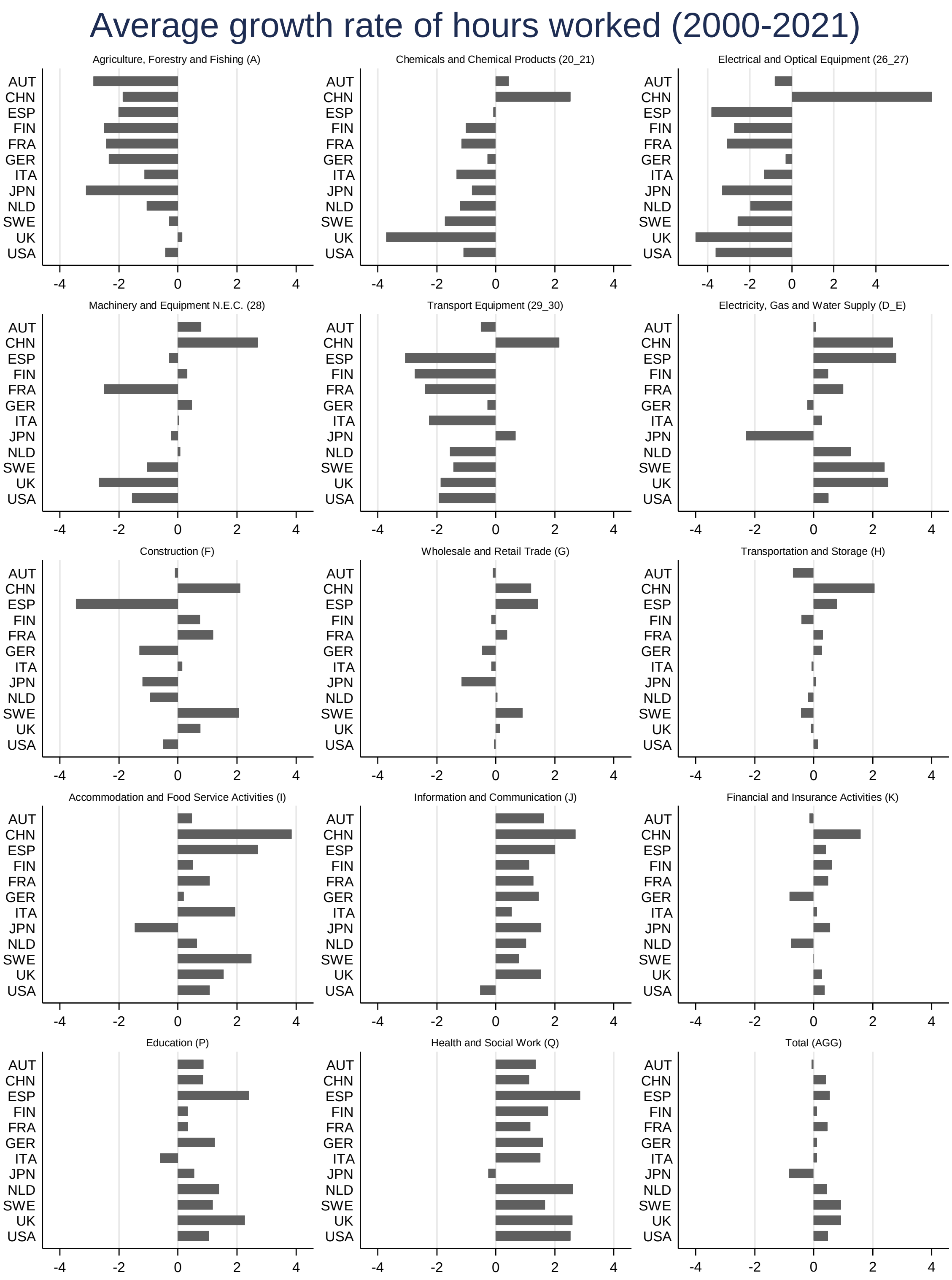


Figure 15: Average growth rate of hours worked (1995-2007)



Notes: Figures display annual average growth rates of hours worked (in percent).

Figure 16: Average growth rate of hours worked (2000-2021)

4.2. Results of econometric modelling

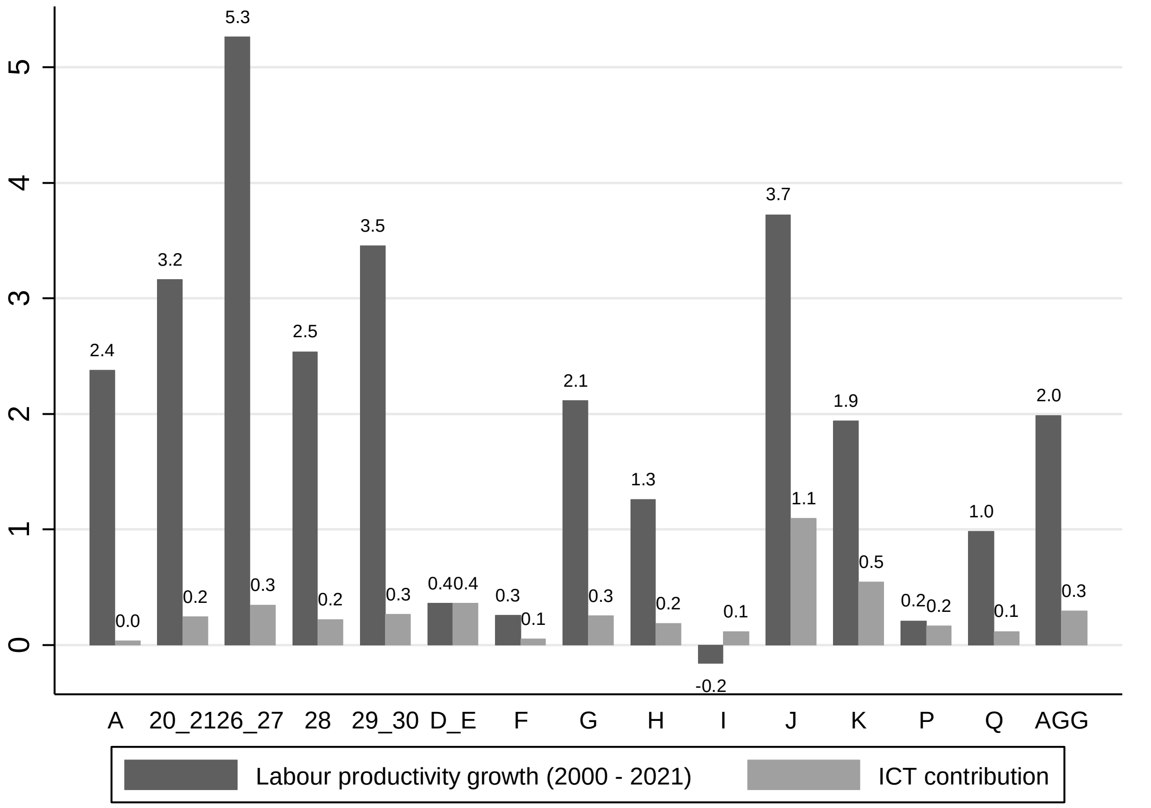


Figure 17: Average observed labour productivity growth rates by industry and the estimated contribution of ICT capital services to it (for the years 2000 to 2021)

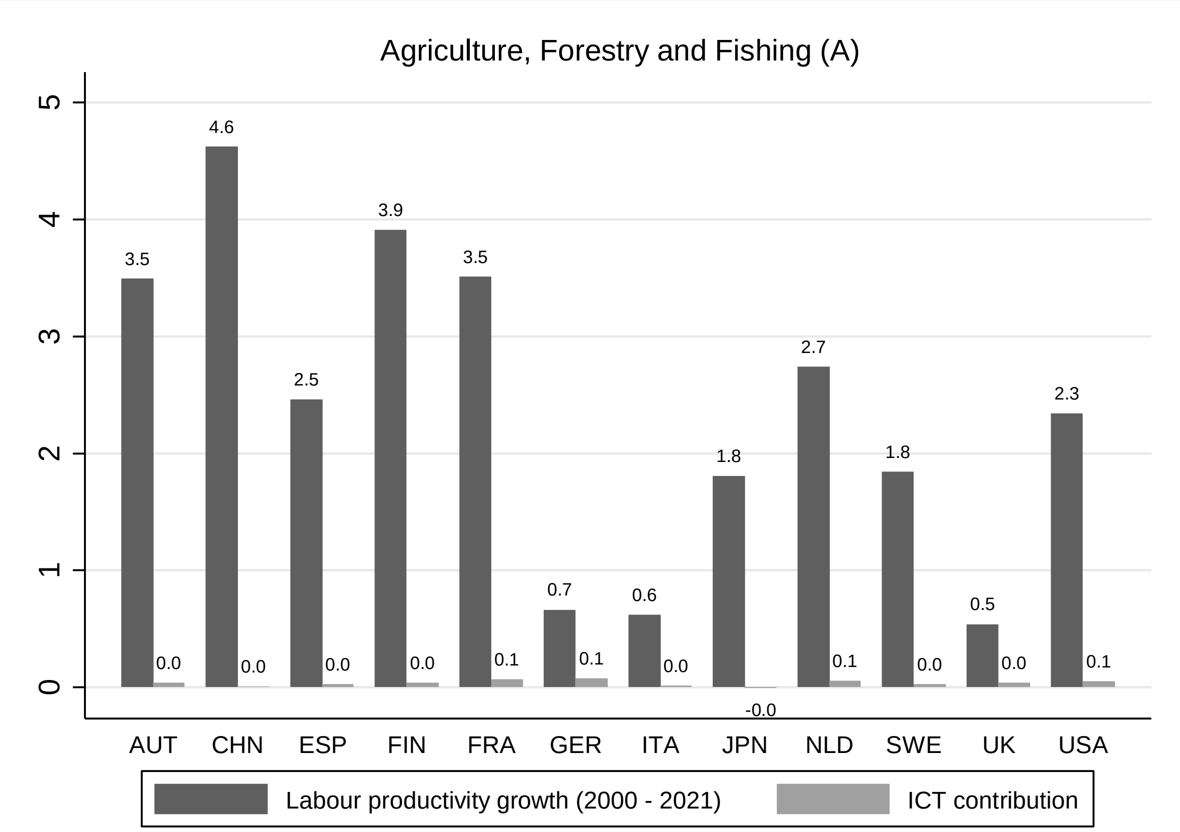


Figure 18: Average observed labour productivity growth rates and the estimated contribution of ICT capital services - (A)

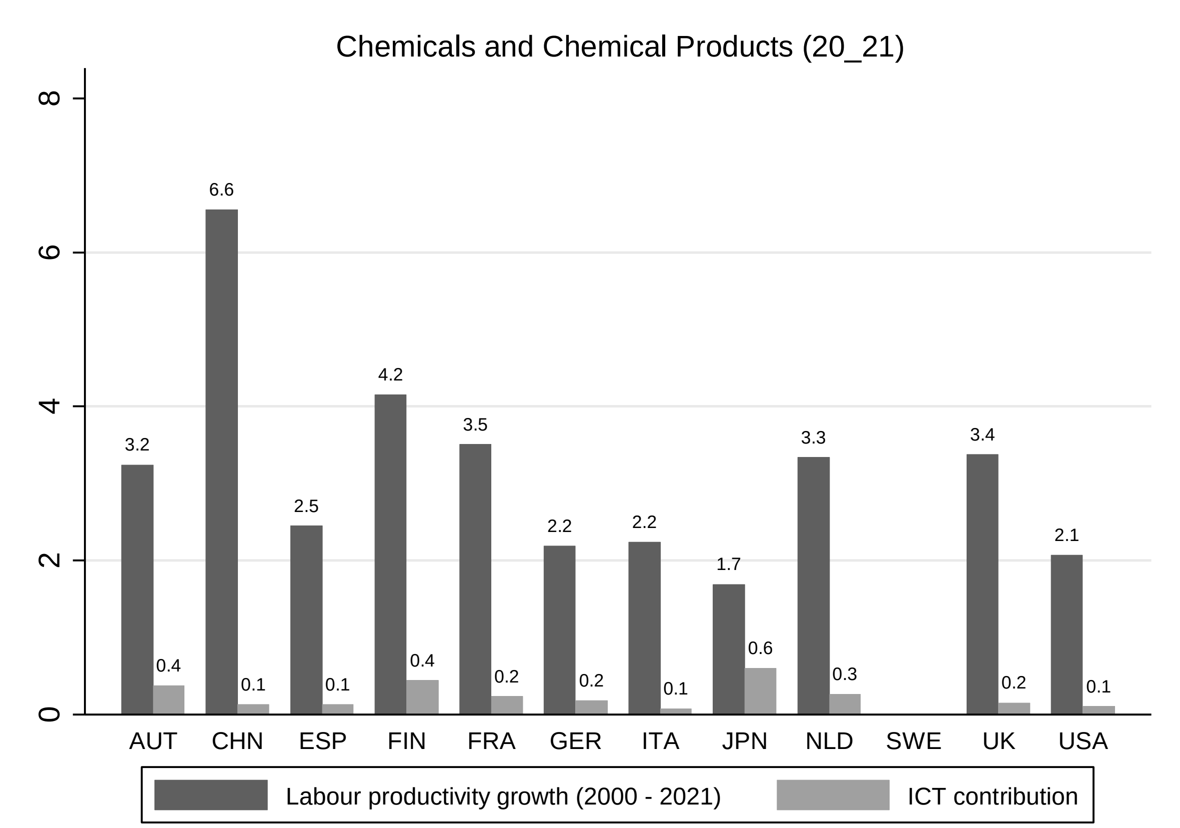


Figure 19: Average observed labour productivity growth rates and the estimated contribution of ICT capital services - (20_21)

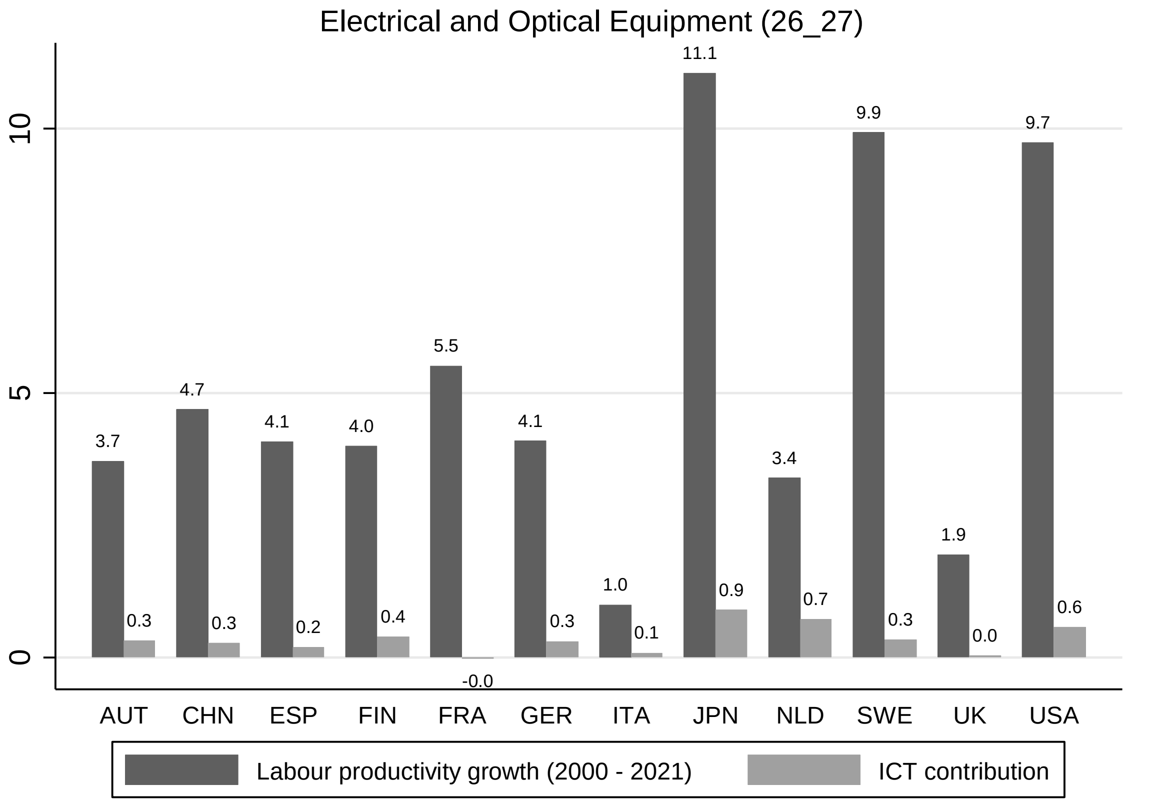


Figure 20: Average observed labour productivity growth rates and the estimated contribution of ICT capital services - (26_27)

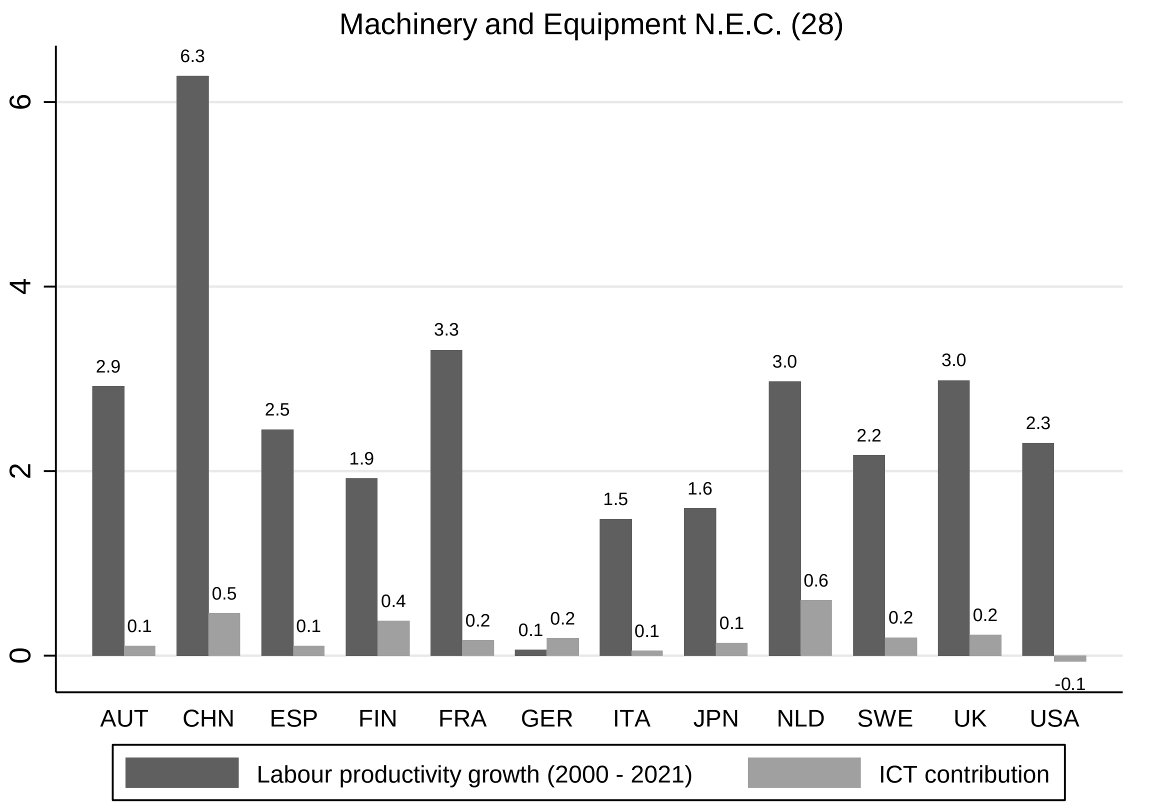


Figure 21: Average observed labour productivity growth rates and the estimated contribution of ICT capital services - (28)

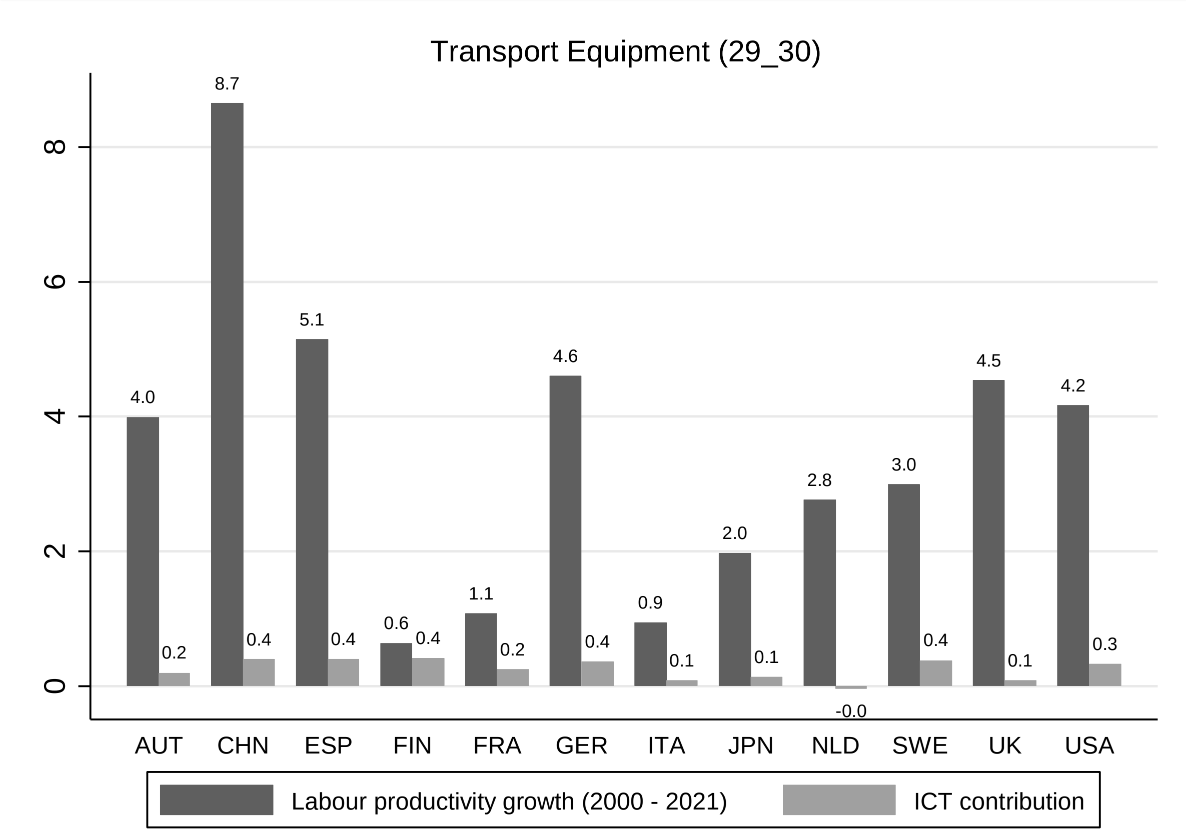


Figure 22: Average observed labour productivity growth rates and the estimated contribution of ICT capital services - (29_30)

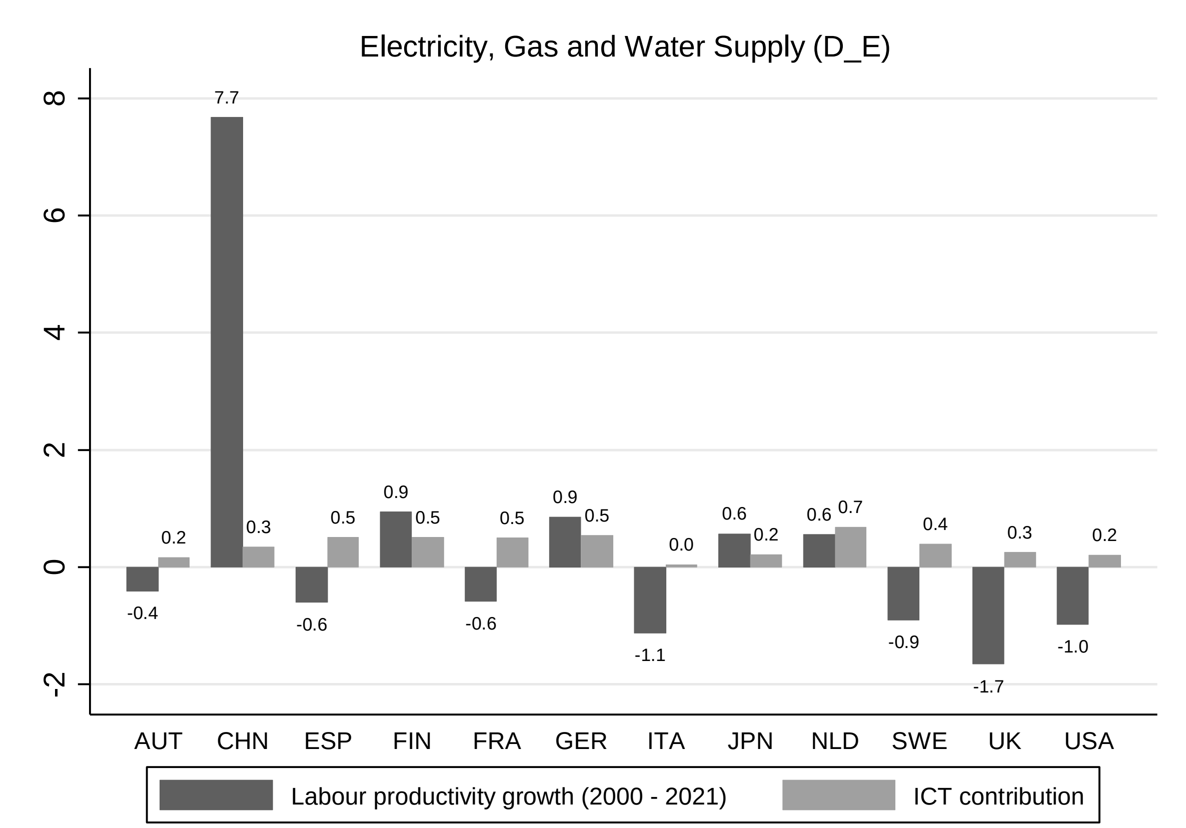


Figure 23: Average observed labour productivity growth rates and the estimated contribution of ICT capital services - (D_E)

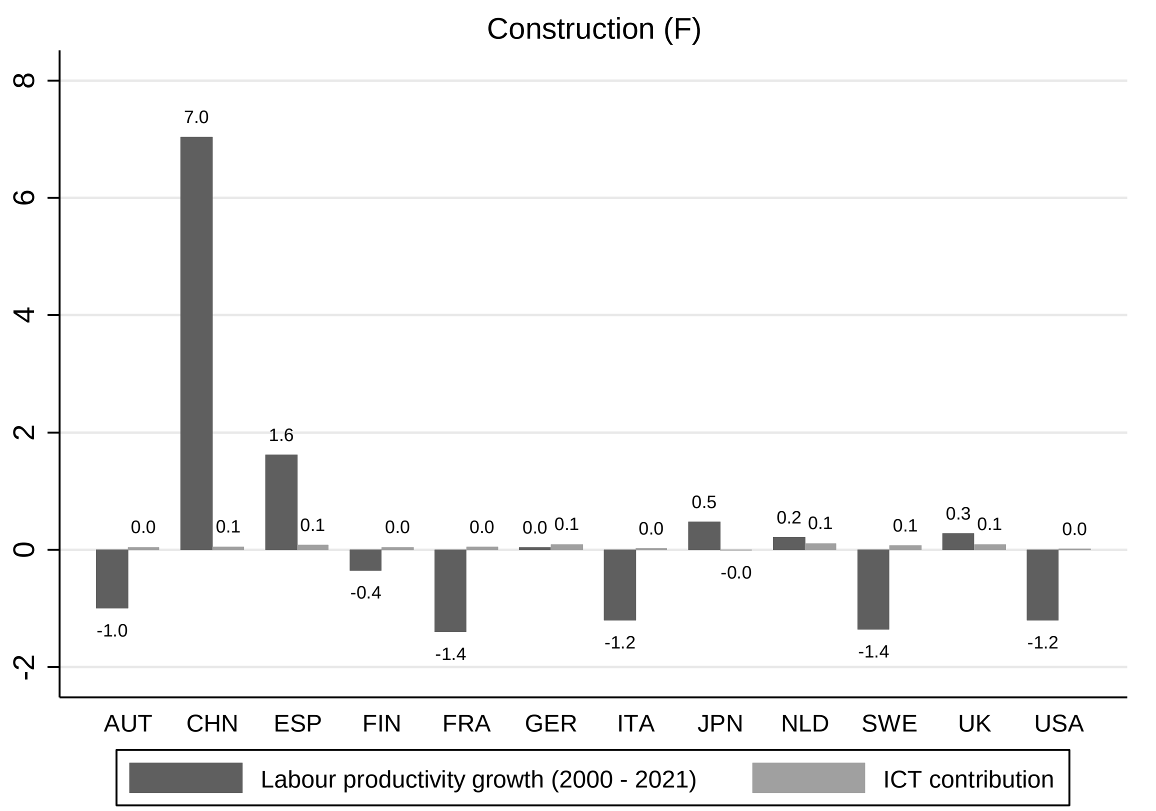


Figure 24: Average observed labour productivity growth rates and the estimated contribution of ICT capital services - (F)

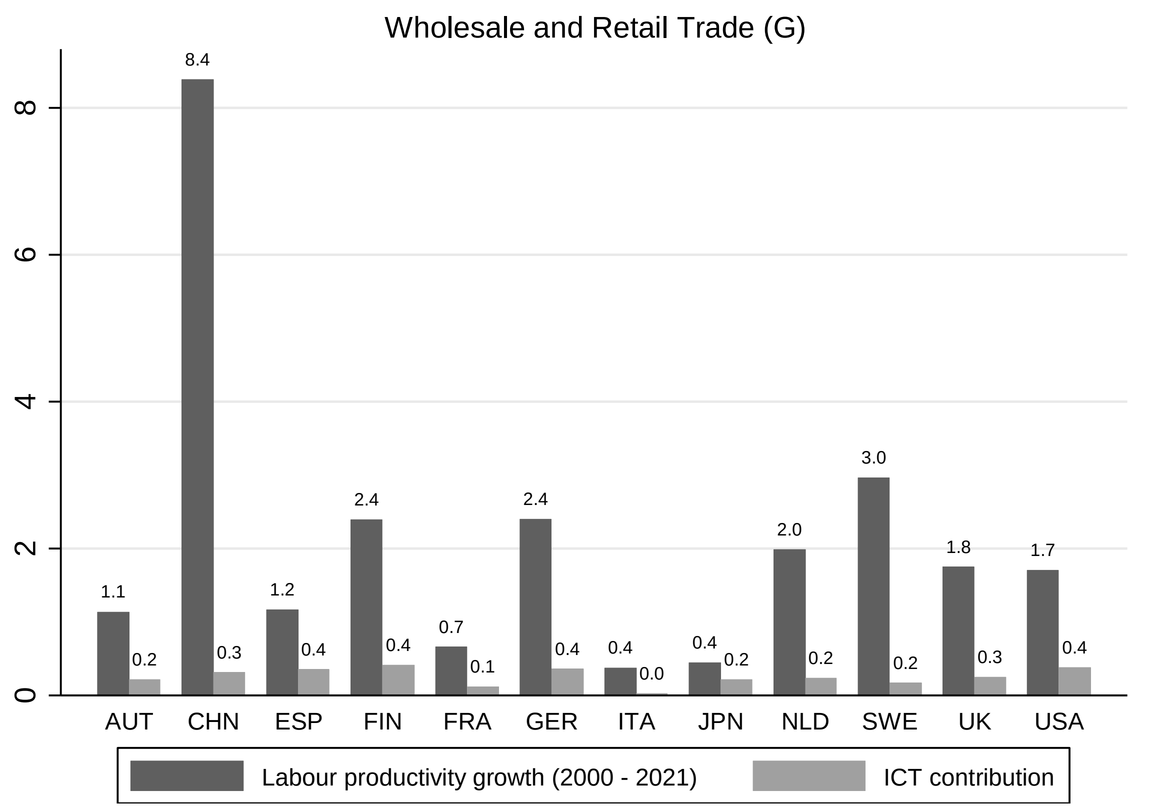


Figure 25: Average observed labour productivity growth rates and the estimated contribution of ICT capital services - (G)

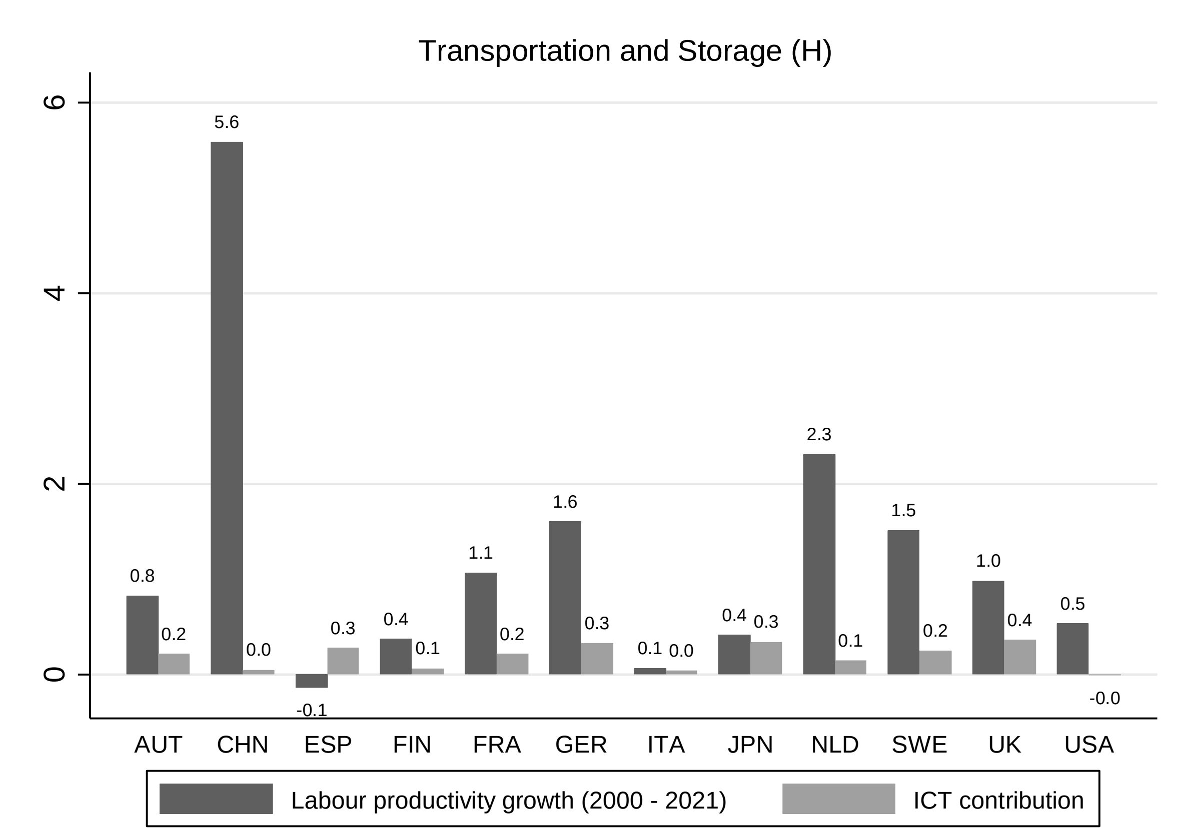


Figure 26: Average observed labour productivity growth rates and the estimated contribution of ICT capital services - (H)

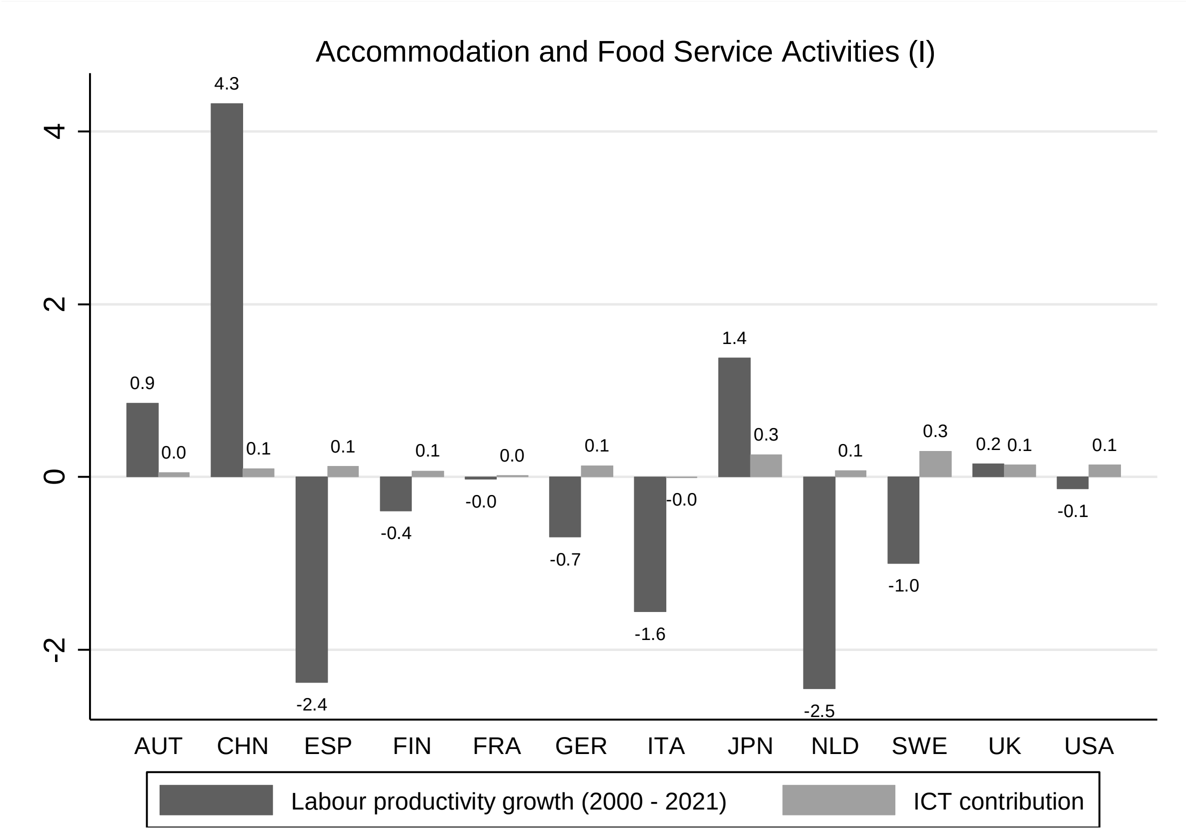


Figure 27: Average observed labour productivity growth rates and the estimated contribution of ICT capital services - (I)

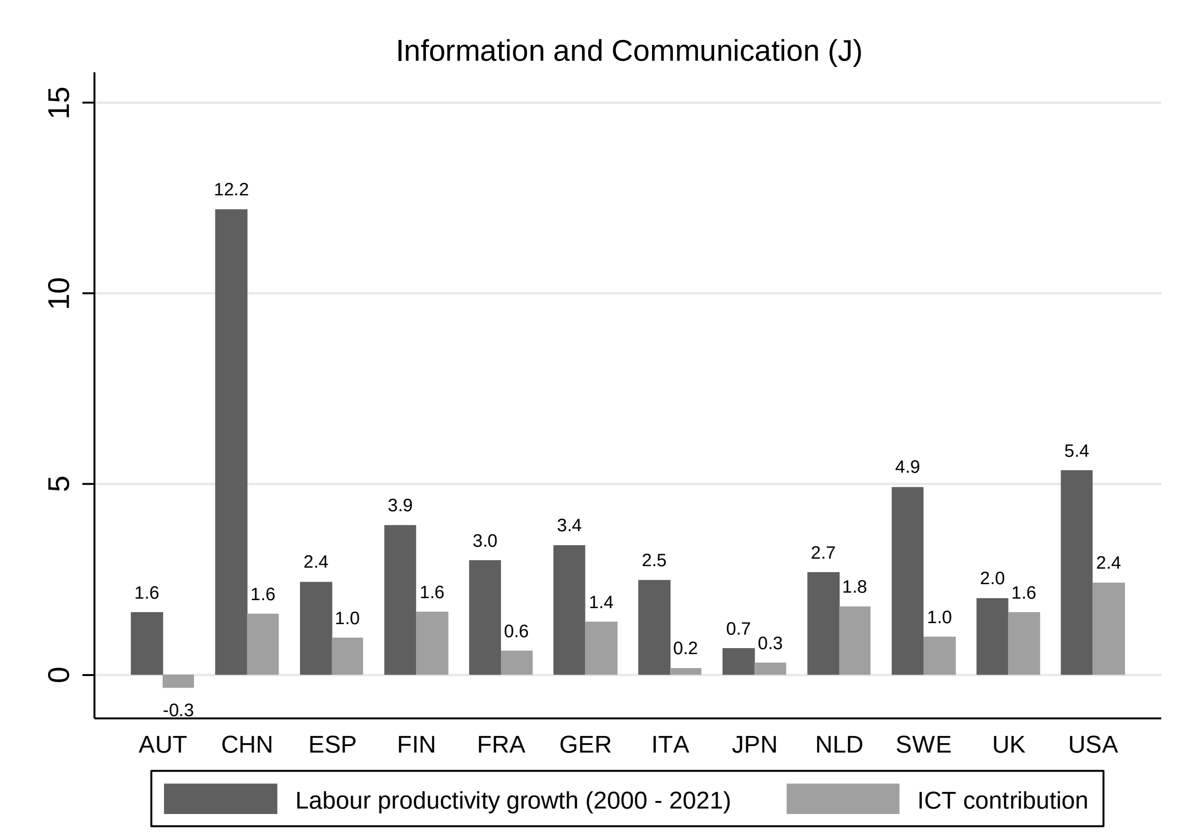


Figure 28: Average observed labour productivity growth rates and the estimated contribution of ICT capital services - (J)

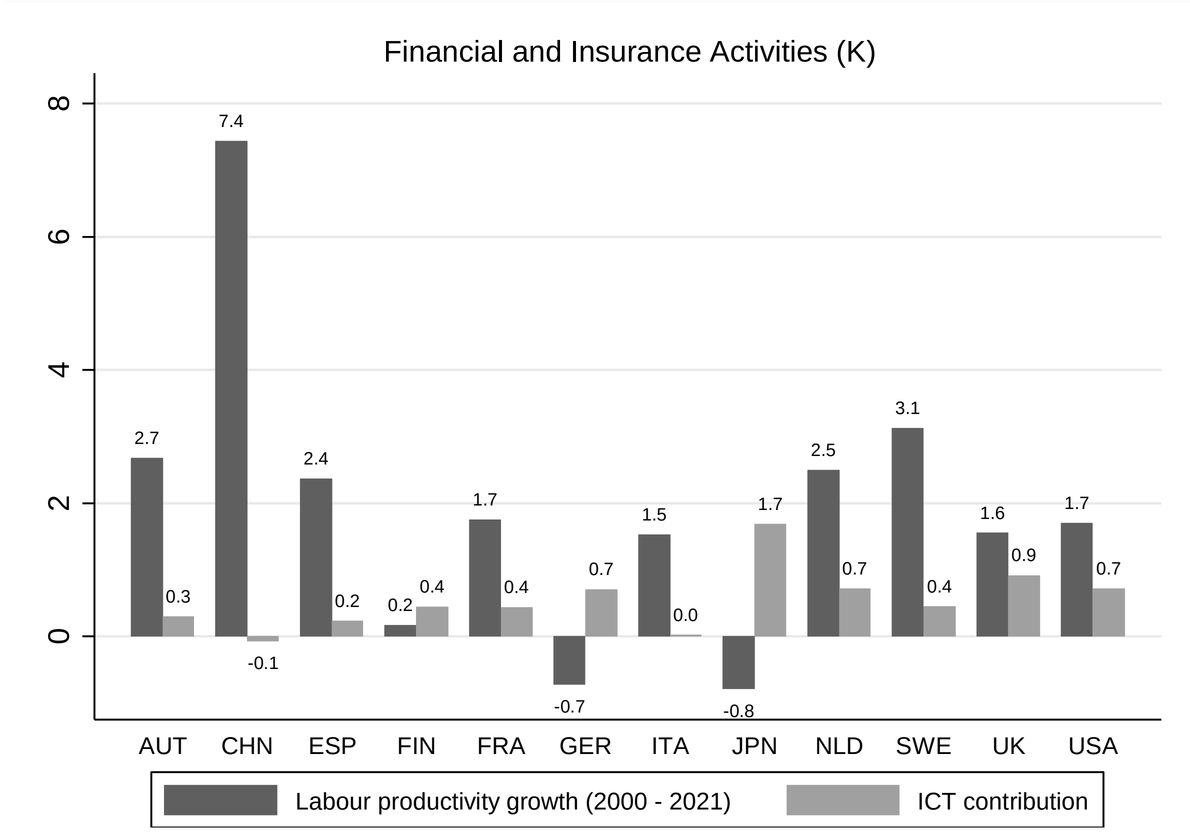


Figure 29: Average observed labour productivity growth rates and the estimated contribution of ICT capital services - (K)

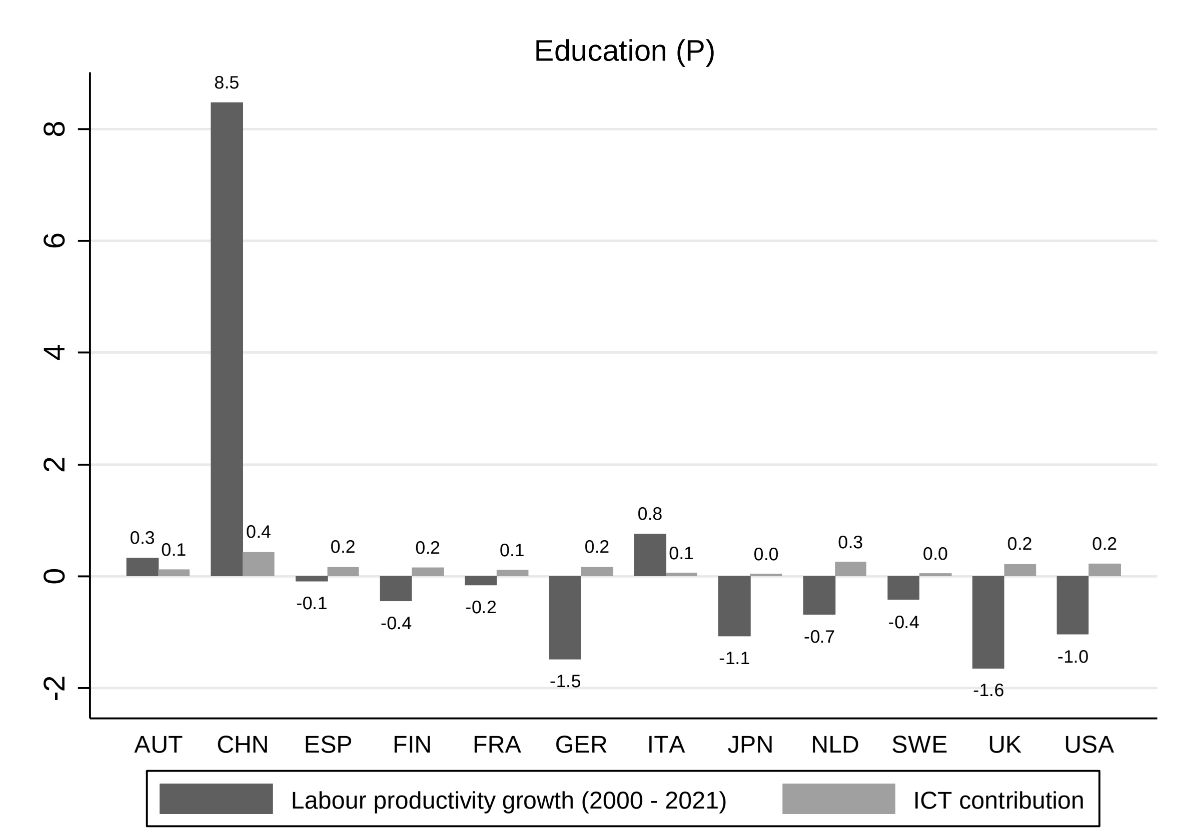


Figure 30: Average observed labour productivity growth rates and the estimated contribution of ICT capital services - (P)

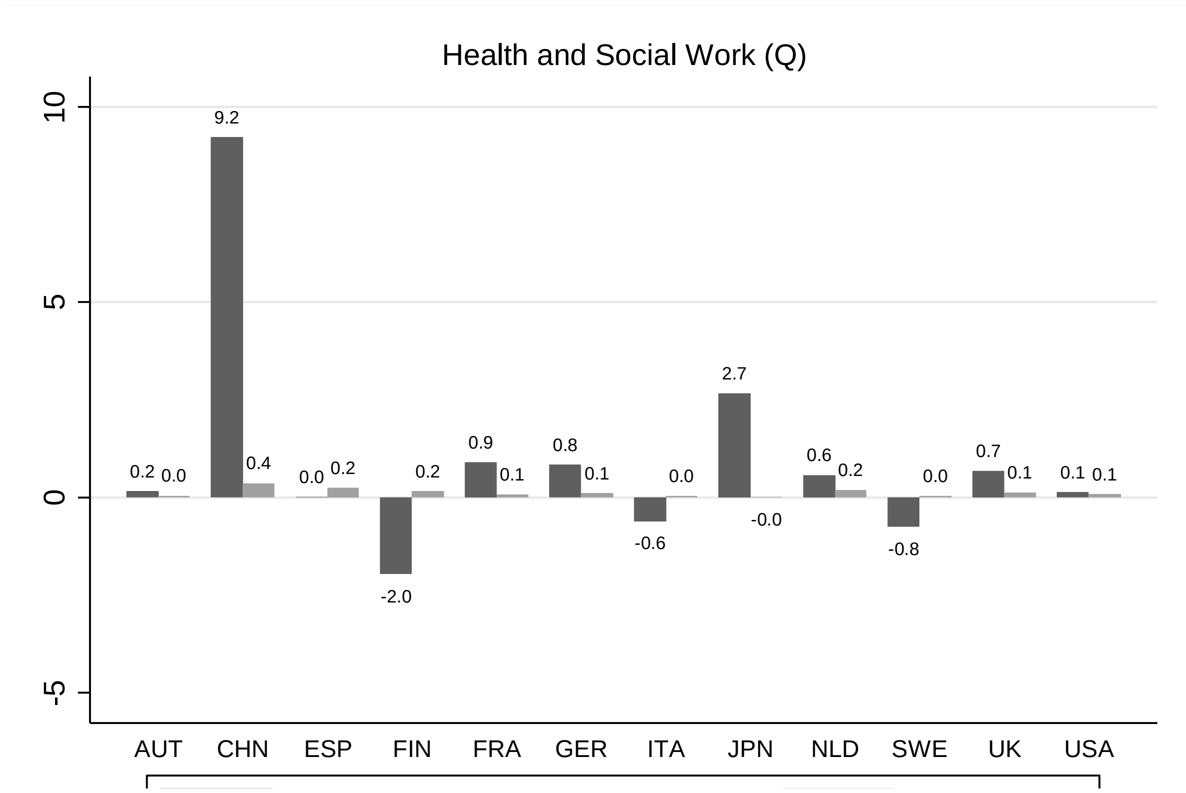


Figure 31: Average observed labour productivity growth rates and the estimated contribution of ICT capital services - (Q)

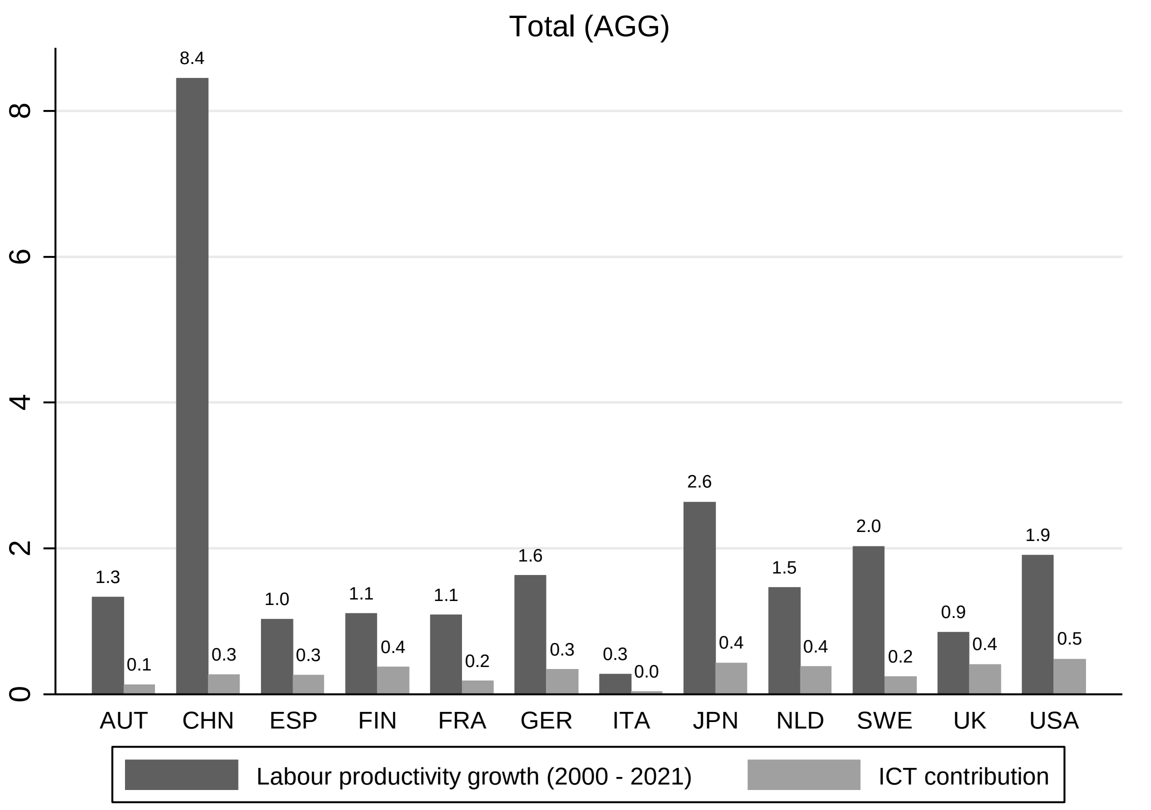


Figure 32: Average observed labour productivity growth rates and the estimated contribution of ICT capital services - (Total - AGG)

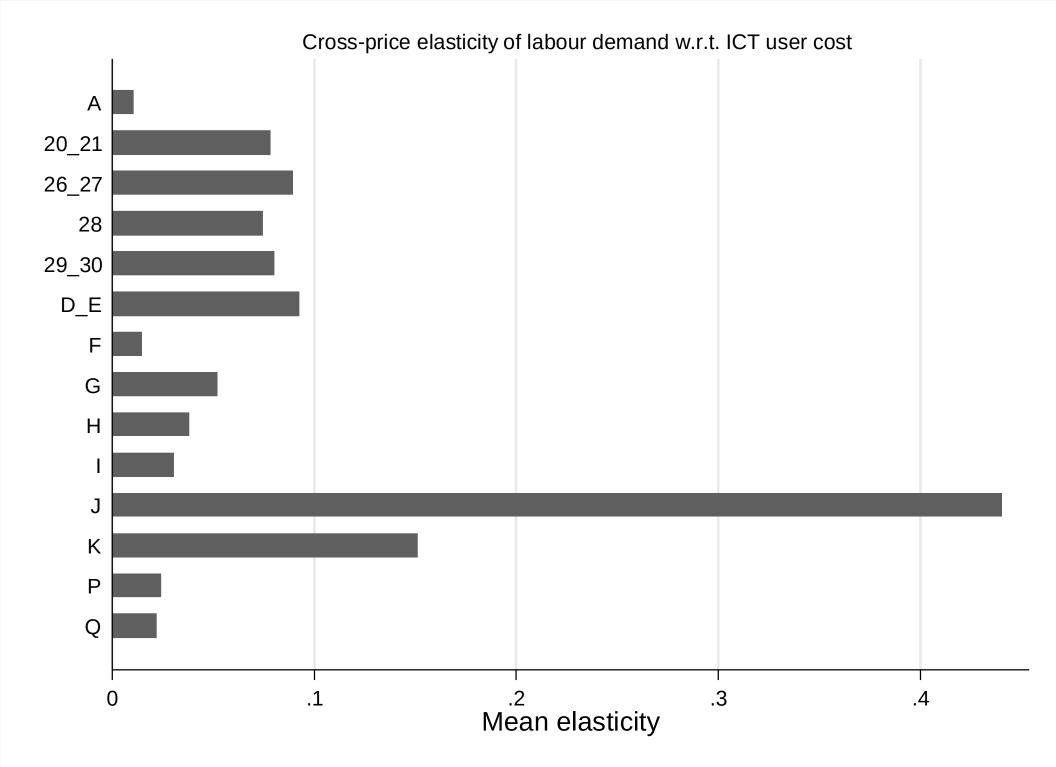


Figure 33: Cross-price elasticity of labour demand with respect to ICT user cost (2000 – 2021)

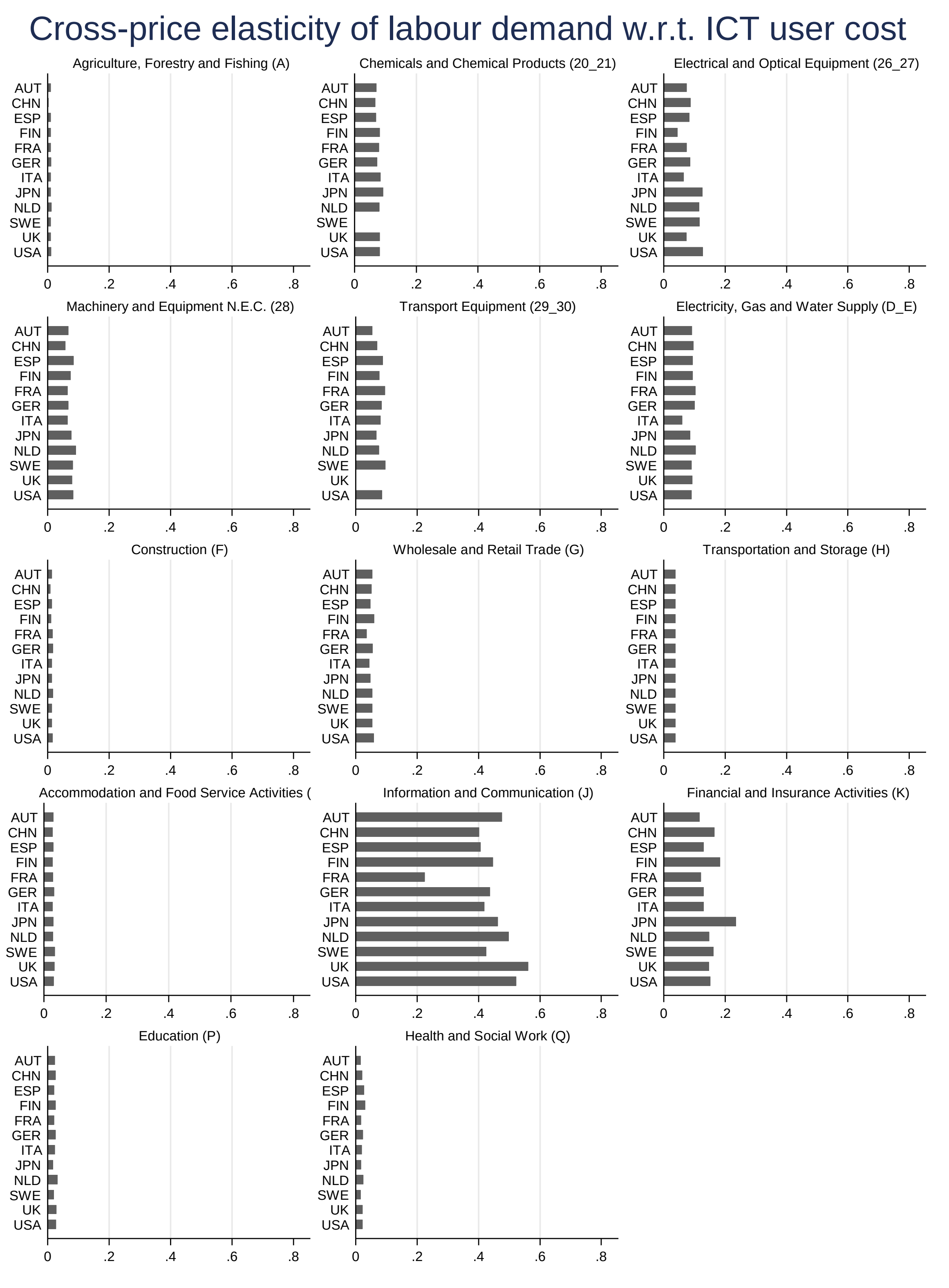


Figure 34: Cross-price elasticity of labour demand with respect to ICT user cost (2000 – 2021)

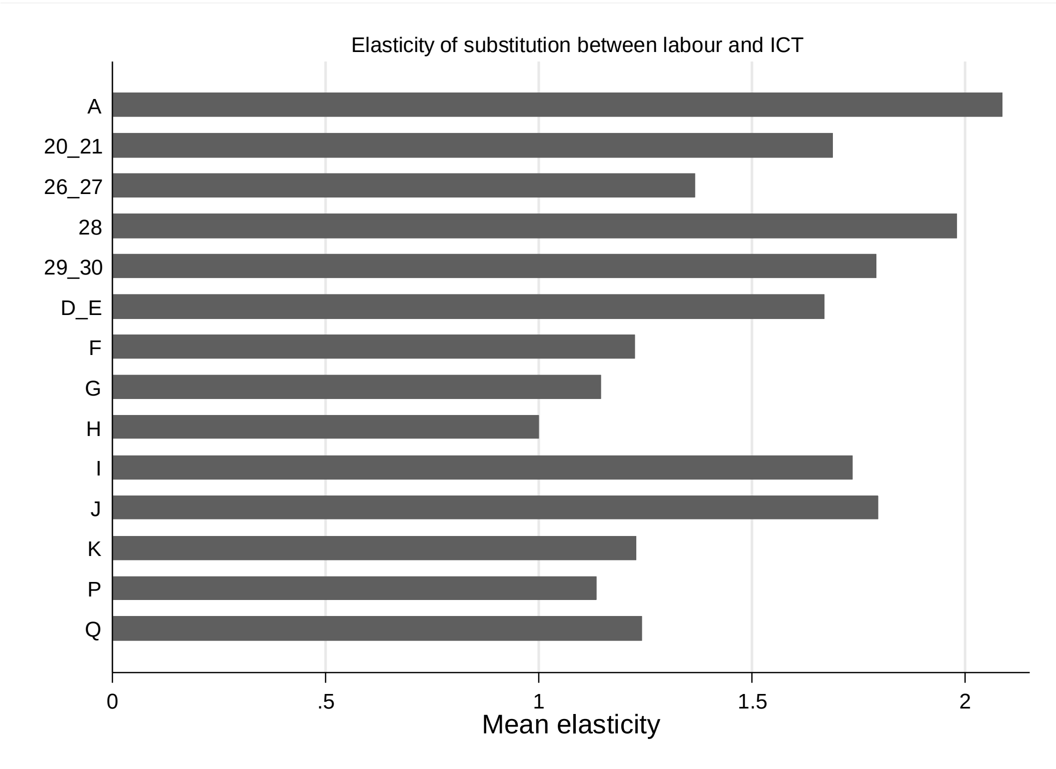


Figure 35: Allen partial elasticity of substitution between labour and ICT (2000 - 2021)

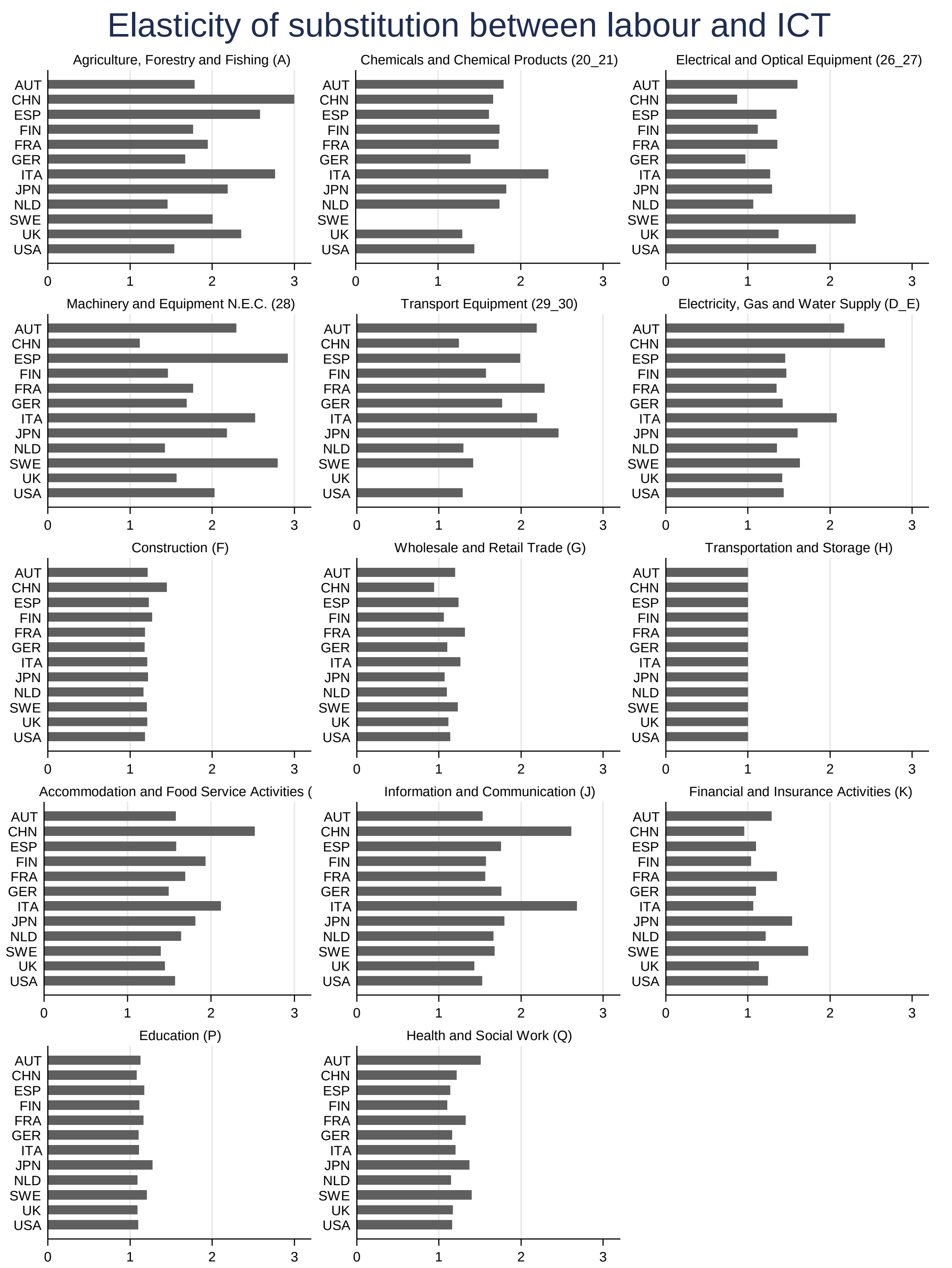


Figure 36: Allen elasticity of substitution between labour and ICT (2000 - 2021)

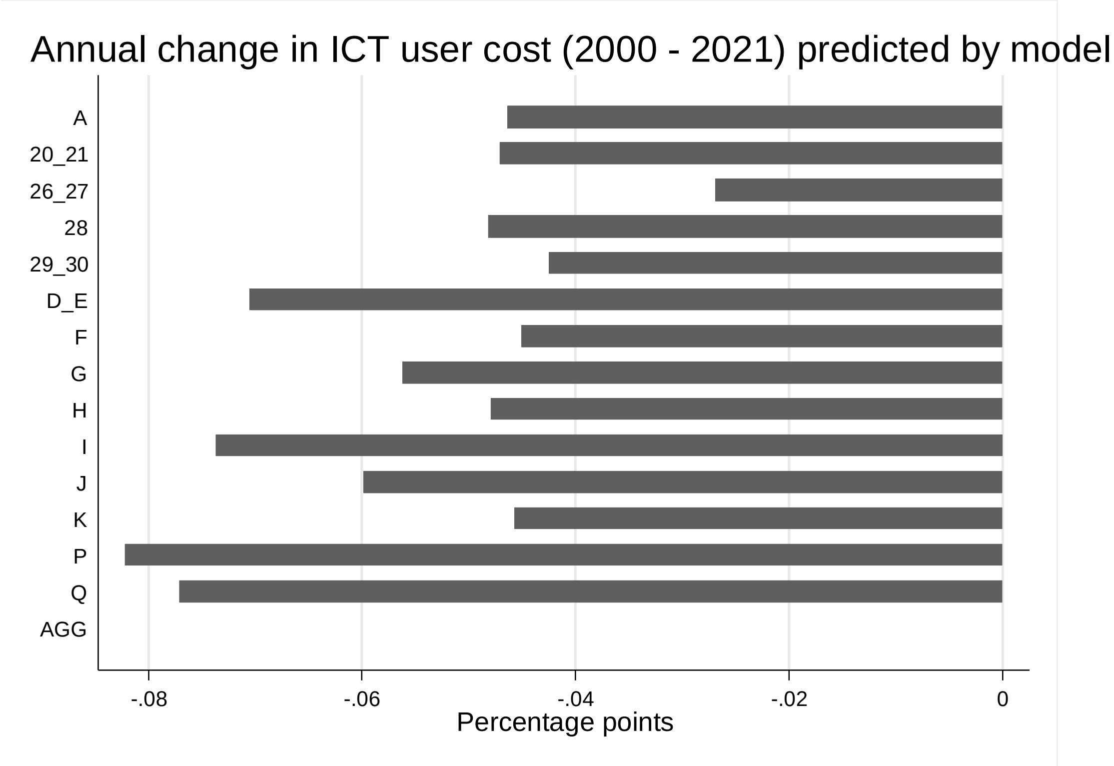


Figure 37: Annual change in ICT user cost (2000 - 2021) predicted by model

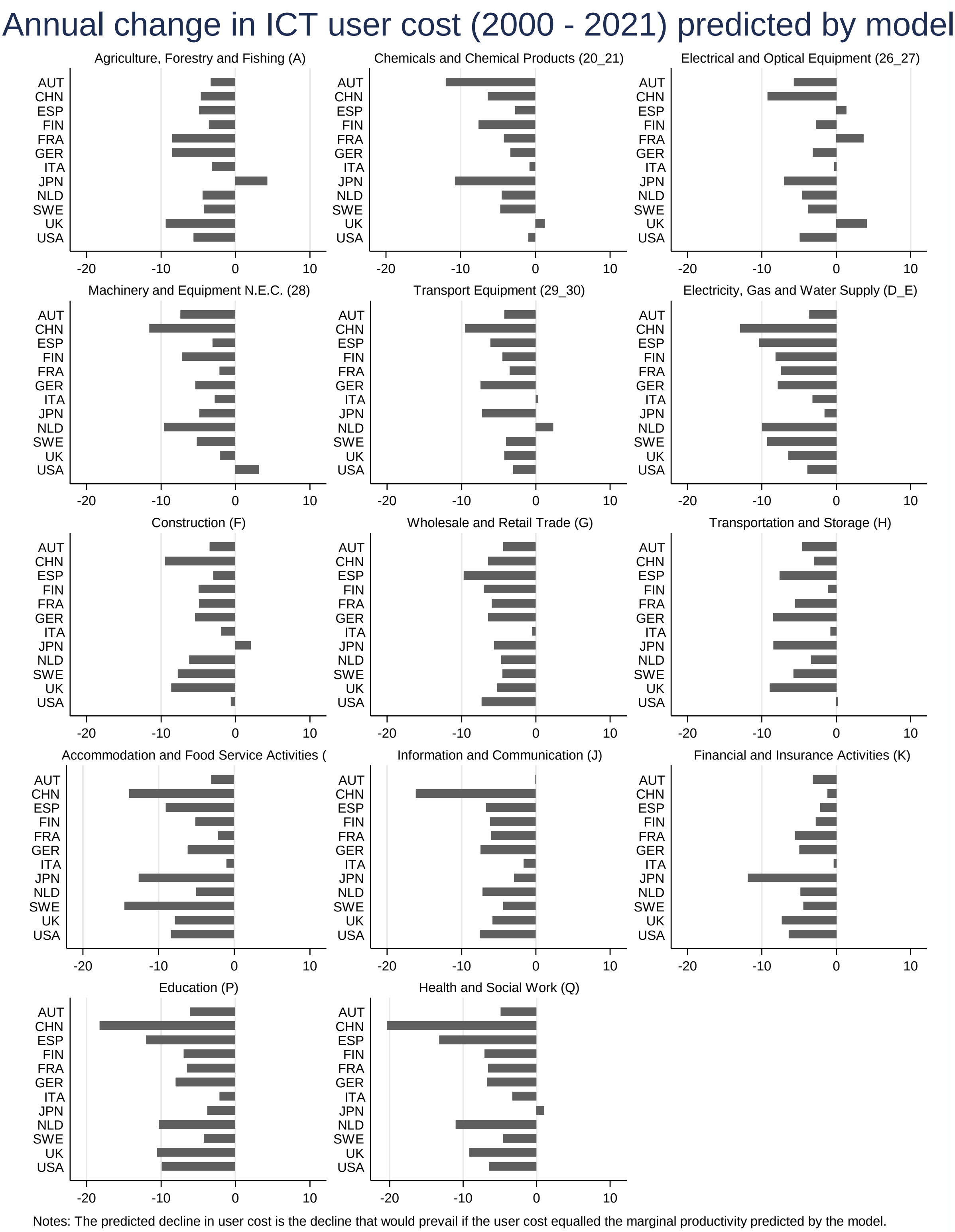


Figure 38: Annual change in ICT user cost (2000 - 2021) predicted by model

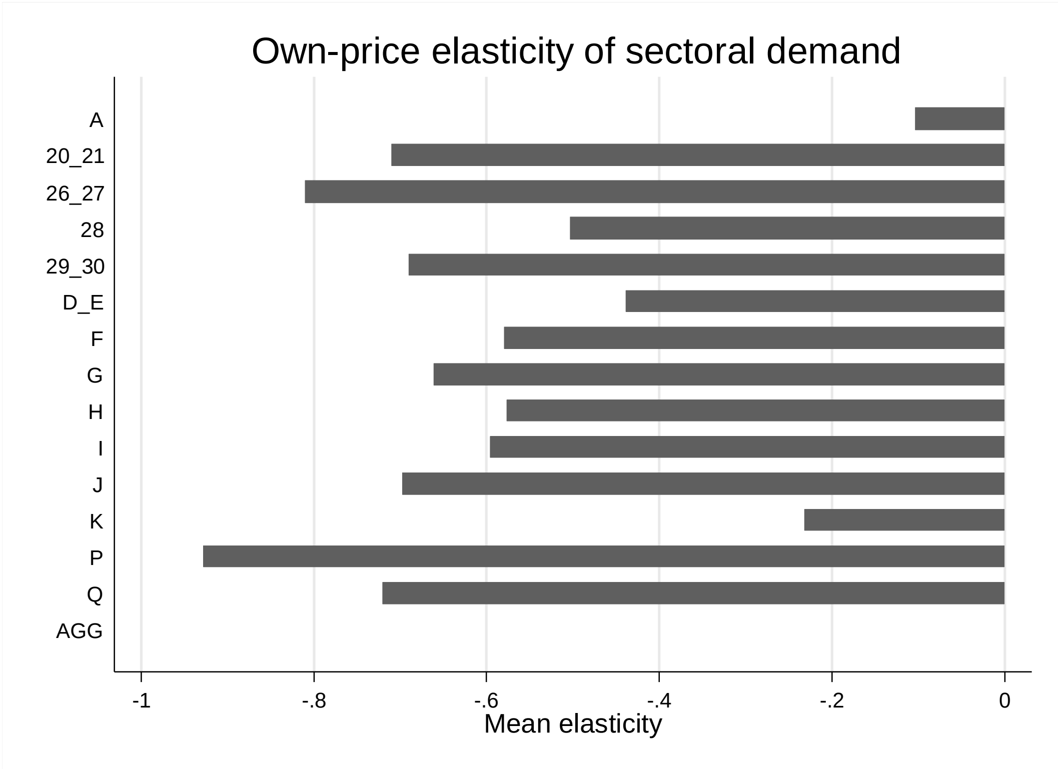


Figure 39: Own-price elasticity of sectoral demand (2000 - 2021)

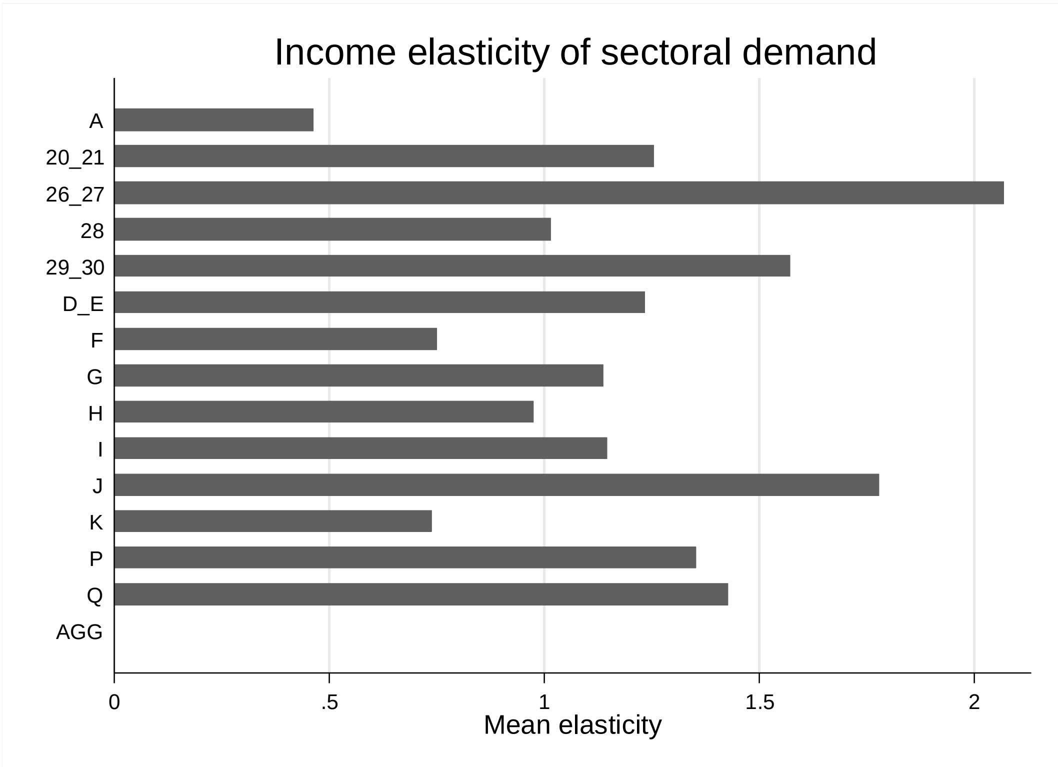


Figure 40: Income elasticity of sectoral demand (2000 - 2021)

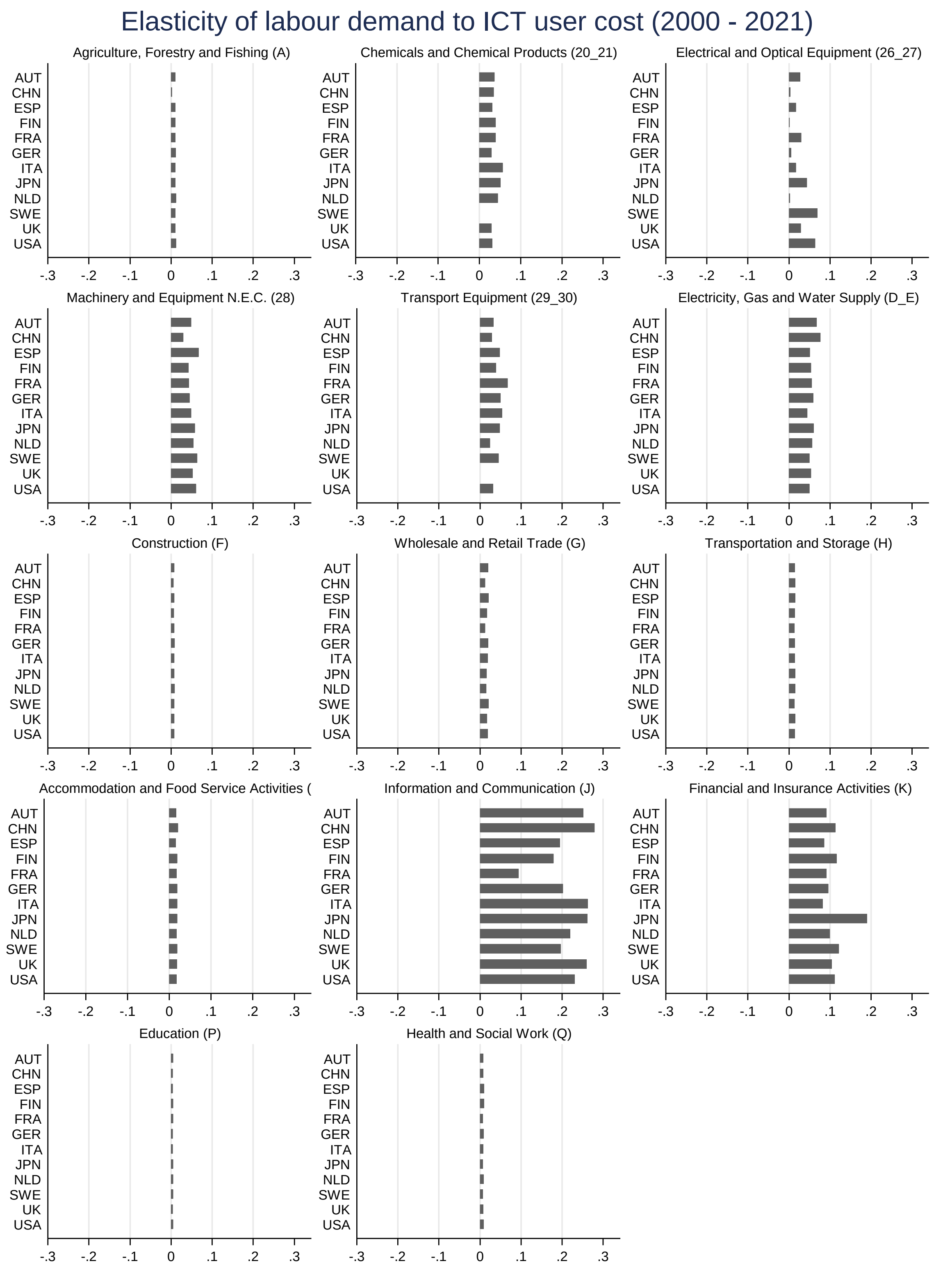


Figure 41: Elasticity of labour demand to ICT user cost (2000 - 2021)

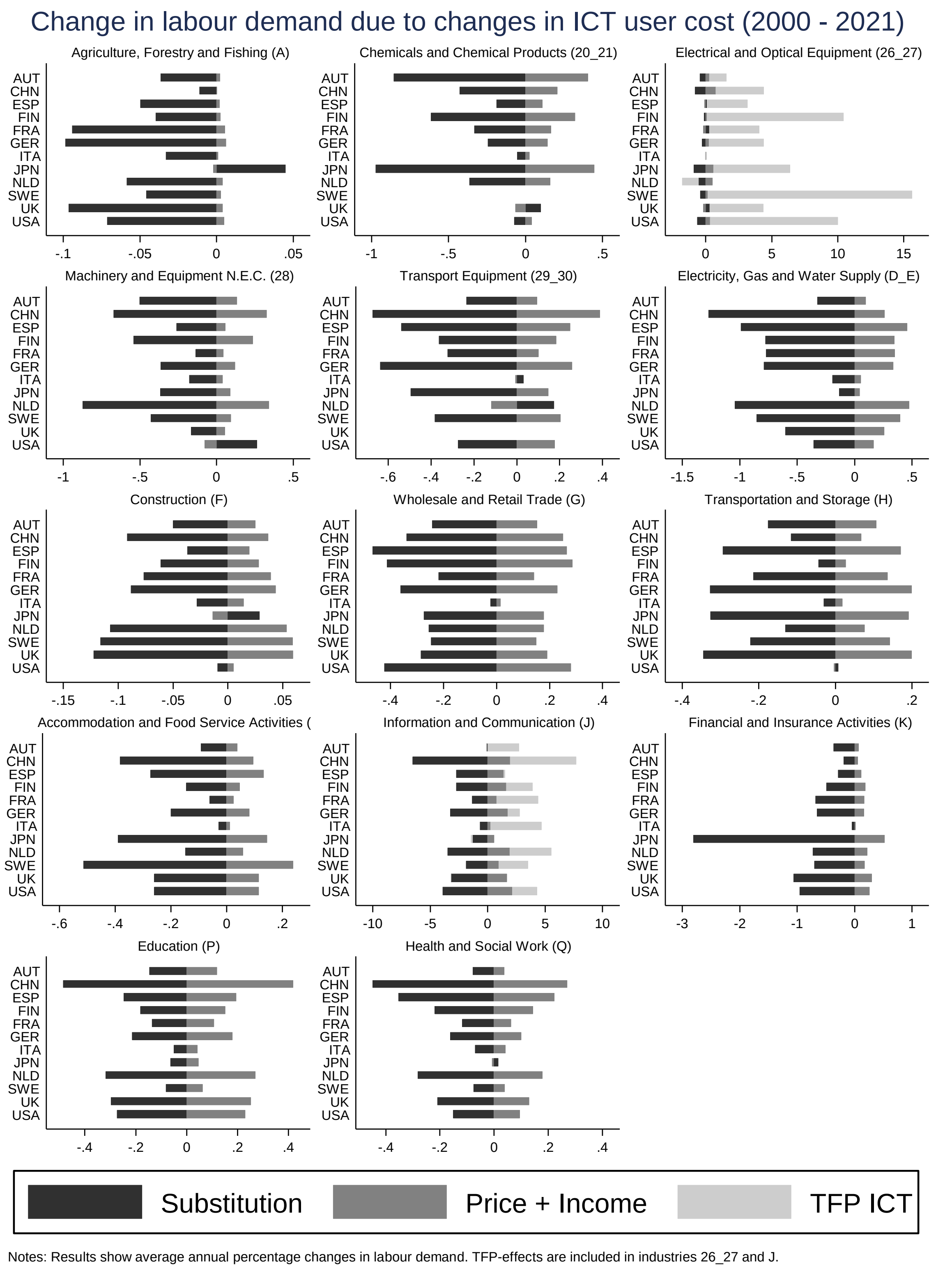


Figure 42: Change in labour demand due to changes in ICT user cost (split into substitution-, price+income-, and TFP-effect), in percent (2000 - 2021)

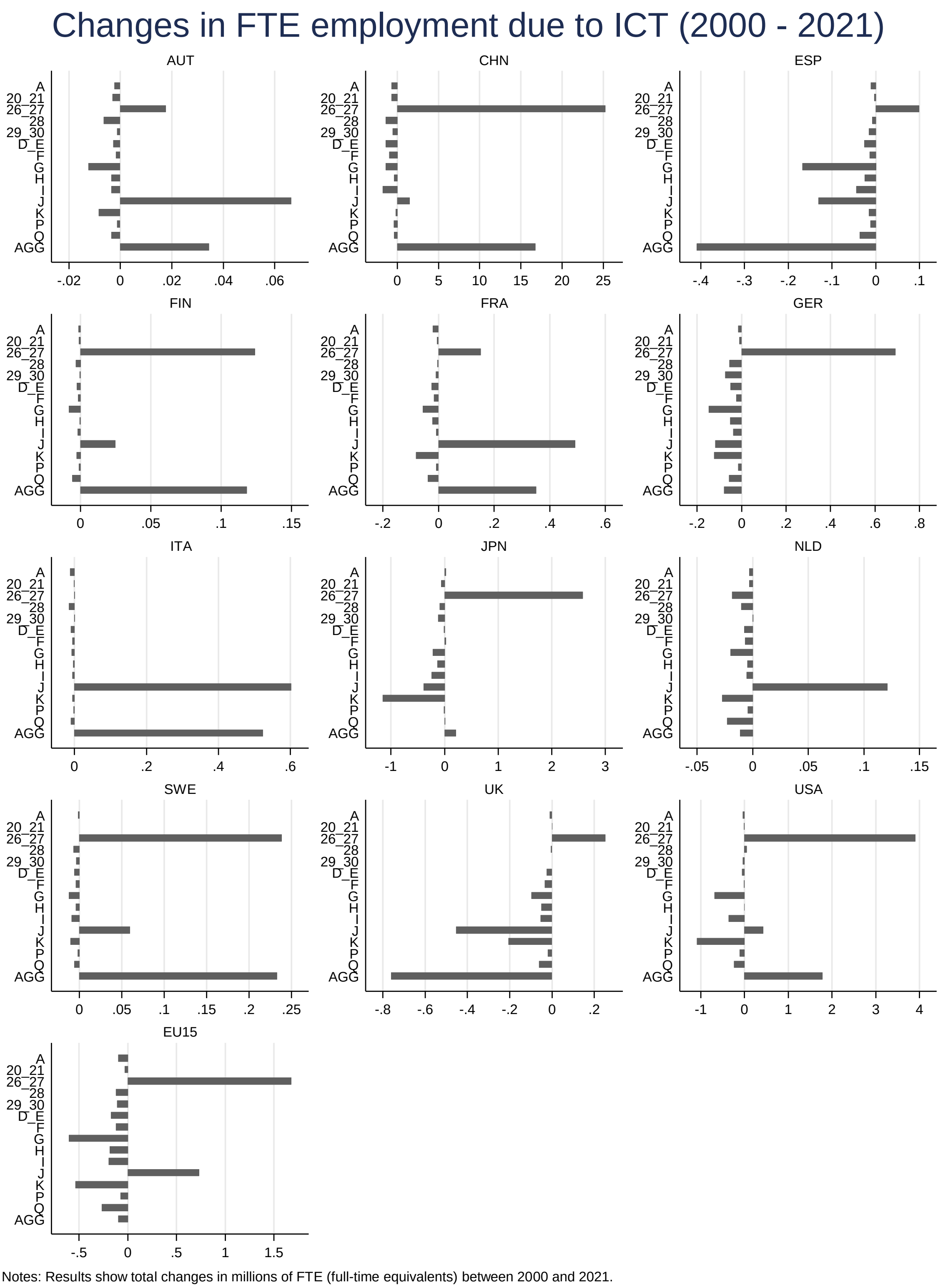


Figure 43: Changes in FTE employment due to ICT (2000 - 2021)

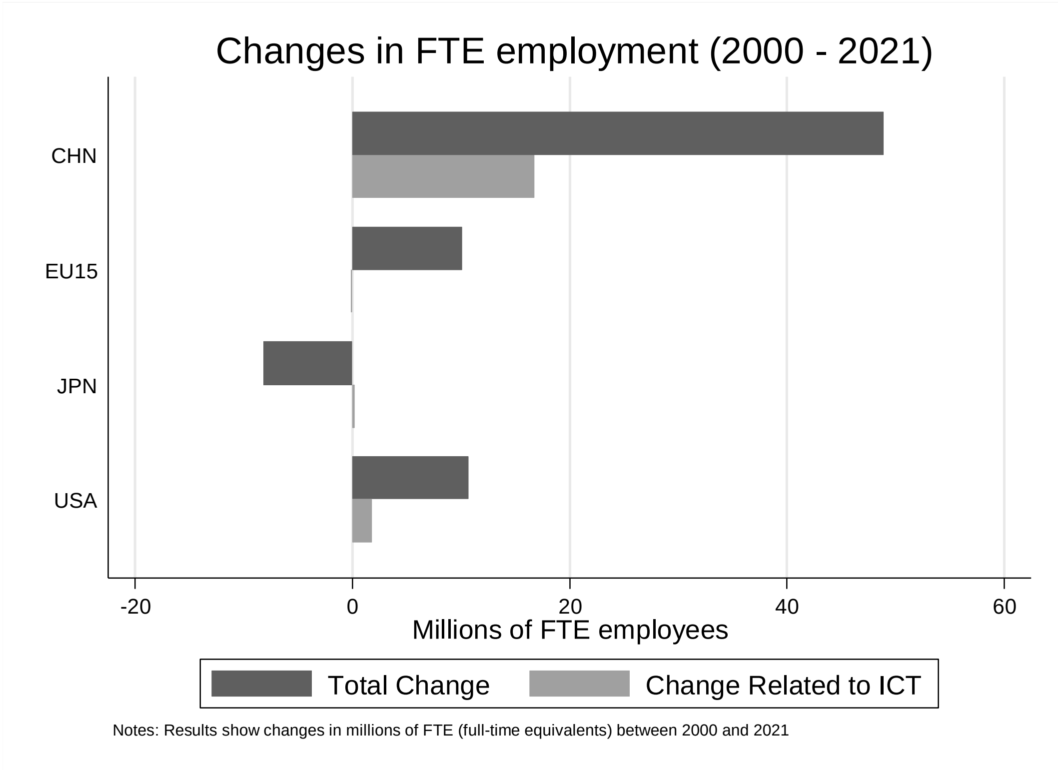


Figure 44: Total changes in employment and changes in employment related to ICT (2000 – 2021) in millions of FTE

5. Discussion of Results

5.1. Evolution of value added and inputs

Among the many changes visible in the evolution of value added, inputs and related variables, the most important ones for the present study are the increase in ICT capital services and the evolution of employment, where the latter is mostly negative in manufacturing and neutral or positive in the service sector.

Average ICT Capital Services Growth Rates

The figures in section 4.1. show the average annual growth rates of ICT capital services for each industry and country for the period 1995 – 2007 and 2000 - 2021. On average, between 1995 and 2007 ICT capital services grew by around 10 percent annually with overall values between 3 and 30 percent. We observe the highest growth rates in industries H (Hotels and Restaurants), M (Health) and N (Education and Social Work) and the lowest growth rates in industries E (Electricity, Gas and Water) and 64 (Post and Telecommunication). Between 2000 and 2021 we observe and forecast lower growth rates, between 0 and 15 percent and a mean value of 5 percent.

Average ICT Capital Compensation Share

The next set of figures describes average country-industry specific ICT capital compensation shares in total factor compensation. On average, the ICT capital compensation share is around 5 percent, but ranges from 0 to 40 percent. Two industries, 64 (Post and Telecommunication) and J (Financial Intermediation), stand out with their high ICT capital compensation share of 10 to 15 percent. These high shares, which indicate that there is already a strong diffusion of ICT, explain part of the relatively low growth rates of ICT capital services in these industries in the following years. This relation is confirmed empirically when computing the correlation between the two variables.

Average Non-ICT Capital Services Growth Rates

In contrast to ICT capital, for non-ICT capital services we observe much lower growth rates, which equal on average 2.5 percent per year and vary between minus 5 and plus 20 percent between 1995 and 2007 and between minus 5 and plus 10 percent between 2000 and 2021. Not too surprisingly China exhibits the highest growth rates.

Average Labour Productivity Growth Rates

The two figures showing average annual labour productivity growth rates by country and industry illustrate a high degree of heterogeneity across countries, industries and time periods. Overall, in the first period between 1995 and 2007 we observe slightly higher average growth rates (around 2.5 percent) than in the second period between 2000 and 2021 (around 2 percent). This can partly be explained by the economic downturn during the second period. Among the sectors, the Electrical and Optical Equipment (30t33) and the Post and Telecommunication (64) industry show the highest growth rates (of roughly 7 percent per year), whereas sectors like Construction (F), Hotels and Restaurants (H) and Education (M) exhibit the lowest average growth rates (lower than one percent on average).

Average Change in Relative Value-Added Prices

These figures show average annual changes in sectoral value-added prices relative to the weighted average value added price change of all industries within a country. To compute the aggregate average output price, we use the nominal value added of industries to weight industry-specific price changes. The figures illustrate a high degree of cross-country and cross-industry heterogeneity in price developments and show that there are industries, like Electrical and Optical Equipment (30t33), Transport Equipment (34t35) or Post and Telecommunication (64) which exhibit negative relative price changes in most countries, whereas in other industries, especially service industries like Hotels and Restaurants (H), Education (M) and Health and Social Work (N) we see mainly relative price increases.

Average Growth Rate of Hours Worked

For labour input, which we measure by the hours worked within an industry, we also observe a very high degree of heterogeneity across countries and industries. Even within industries, often several countries exhibit growth in the hours worked whereas other countries see a decline of hours worked in the same industries. A few industries exhibit clear patterns: the Agriculture (AtB) industry exhibits a clear decrease in hours worked. In contrast, industries like Hotels and Restaurants (H), Education (M) and Health and Social Work (N) see an increase in hours worked in most countries.

Summary Remarks

Though the detailed picture is largely heterogeneous, we see that manufacturing has a tendency to a decline in both relative prices and employment while the service sectors has seen rising rise in both. Though at first sight we might not suspect large-scale job creation due to ICT-related price decline, it may still be the case that price decline has prevented more widespread job destruction in the manufacturing sector.

5.2. Effect of digitisation on productivity growth and employment

The key elements for understanding the main effects identified in the study are

- the equation of the elasticity of labour demand with respect to ICT user cost presented in section 3.4 (following the approach by OECD, 2016)
- the empirical elasticity of labour demand with respect to ICT user cost estimated by the model, presented in Figure 41
- the overall estimated employment effect of ICT in Figure 42.

Figure 16 shows observed average annual labour productivity growth rates by sector and the contribution of ICT capital services to them. It covers the period between 2000 and 2021 and highlights a large sectoral heterogeneity both with respect to the observed labour productivity developments as well as with respect to the contribution of ICT to it. The average annual productivity growth rates range from minus 0.2 percent (Accommodation and Food Service Activities) to plus 5.3 percent (Electrical and Optical Equipment). The largest absolute contribution of ICT capital services is observed in industry J (Information and Communication) where ICT capital services annually contribute 1.1 percentage points to labour productivity growth. The lowest contribution of ICT capital services (close to zero) is observed in industry A (Agriculture, Forestry and Fishing). Overall, for the aggregate economy (i.e. the aggregate of the 14 industries considered) we observe an average annual labour productivity growth of 2 percent and an ICT contribution of 0.3 percentage points.

This figure also reveals that, while being important in some sectors, the ICT contribution to labour productivity growth in fast growing sectors is well below half. From the literature it is known that the large part of the remaining productivity growth represents TFP growth. The figure thus also reflects the high TFP growth in ICT-producing sectors (26t27 and J), which we have included in the computation of ICT-related employment effects. Figures 17 to 31 present detailed results on labour productivity growth by sector and country.

Figure 33 shows the cross-price elasticity of labour demand with respect to ICT user cost, which reflects the substitution effect of digitisation. This is the product of the output elasticity of ICT and the Allen elasticity of substitution between labour and ICT. The cross-price elasticity generally lies well below 10 percent. This means, at constant output, a 10 percent decline in user cost results in a reduction in employment of less than one percent. The elasticity is low in the sectors Agriculture (A), Construction (F), Transport and Storage (H), Accommodation and Food Services (I), Education (P) and Health and Social Work (Q). It displays medium values in the manufacturing sectors (21-30), Trade (G) and Electricity, Gas and Water Supply (D_E) and very high values in the Information and Communication sector (J) and Finance (K). While also reflecting some difference in the elasticity of substitution, these differences are mainly driven by the output elasticity. Under cost minimisation, it equals the ICT cost share. In sum, job losses resulting from further digitisation are, at constant output, to be expected particularly in those sectors in which ICT is already an important input compared to other inputs. This is largely the case in the Information and Communication (J) and Finance (K) service sectors. The output elasticities found there exceed the cost shares.

There is some variation of cross-price elasticities across countries, but in the sectors with small and medium values, these variations do not contribute much to differences in employment effects (Figure 34).

The Allen elasticity of substitution between ICT and labour (Figure 35) exhibits a pattern that is somewhat different from the cross-price elasticity. It is high in the Information and Communication (J) and Finance (K) service sectors, which have a high cross-price elasticity, but also in Agriculture (A) and Production of Machinery and Equipment, which do not. With the exception of sectors J and K, the elasticity of substitution tends to be higher in the production of goods than in services. Along the translog function, the Allen elasticity of substitution has a tendency to fall with the output elasticity (this is not globally true, but for many empirical values). Thus, we do not know whether the high elasticities in goods production will persist once the income share of ICT in total factor input will rise. But if this were the case, this would indicate a higher risk of job loss in the goods-producing sectors, at constant output, than in most of the service sector.

A certain amount of the country variation in the Allen elasticity (Figure 36) is driven by countries with low ICT levels displaying higher elasticities (e.g. Italy and China in sectors A, D_E, I and J). The country variation in the Machinery and Equipment sector (28) seems to be driven by other factors. We consider the country differences as less reliable than the sectoral differences.

Figure 37 summarises the annual change in ICT user cost predicted by the model in different sectors. This change reflects the investment in ICT and the extent of cost reduction that the model predicts for these investments. We see some catching up here, since sectors with very low initial ICT shares (e.g. A, F, P and Q) do not display a strong reduction in predicted user cost. However, the sectors with the highest initial ICT shares (I and J) also display above average decline in predicted user cost of ICT.

We see substantial heterogeneity in the changes in predicted user cost by country (Figure 38). This is also the main driver of cross-country differences in the results. Not all countries invest in ICT to the same extent and depending on where they currently are on the production function, this investment is also associated with different predicted cost reductions. China displays a particularly high level of decline in predicted user costs in a number of sectors, which may be associated with its low initial level of ICT. Italy is known to have very low ICT investment. Japan also displays high values in a number of sectors (20_21, 26_27, I, K), which reflects high growth in ICT capital services (see Figure 6).

The results so far are derived from the production function. We now include the demand effects. The own-price elasticity of sectoral product demand assumes values between -0.4 percent and -0.7 percent in most of the sectors. These values are lower than those found by the OECD (2016), but the magnitude and dispersion of values are plausible when compared to the other studies surveyed. The price elasticities in the manufacturing sectors (21-30) as well as in Trade (G), Transportation and Storage (H) and Accommodation and Food Service Activities (I) reach mostly medium values, with the Chemical Industry (20_21) and the Production of Electrical and Optical Equipment (26_27) at the higher end. The highest own-price elasticity is observed in Education (P). Very low values are found for Agriculture (A) and Finance (K). The third lowest value is observed in Electricity, Gas and Water Supply (D_E).

One challenge in understanding these sectoral results is that the aggregate price elasticity is equal to one according to theory, since aggregate price index reductions translate one-to-one to aggregate real income. One would intuitively expect sectoral price elasticities to be dispersed around the value of one, which is not the case. One reason might be that an aggregate demand function is not simply a weighted mean of sectoral functions and that, moreover, we are neglecting the cross-price effects (which are in some way analogous to the cross-industry effects estimated in Autor and Salomons, 2017). But given the low number of observations, the cross-price effects are estimated in a strongly restricted way. The estimation of the QUAIDS system, which allows for individual cross-price elasticities to be estimated, did not deliver more plausible results.

It is important to recall that the demand function has to be considered with certain caveats related to considering value added instead of gross output, to mixing final and intermediate demand and to neglecting international trade. A very rough sensitivity analysis with an approximated world price deflator for tradable sectors did not reveal vast differences, but this issue could not be fully explored given that the compilation of the necessary trade data was beyond the scope of the project and in part also not possible due to a lack of sources.

The income elasticity of sectoral product demand (Figure 40) is also lowest in Agriculture (A) and Finance (K) but displays a somewhat different pattern in the remaining sectors. It is highest in the ICT sectors (26_27 and J) and relatively low in construction (F). Sectors beyond ICT which have both medium-to-high income and price elasticities are the Chemical

Industry (20_21), the Production of Machinery and Equipment (29_30), Education (P) and Health and Social Work (Q). The last two are mainly driven by government and private demand while the first two are driven to a larger extent by firms' demand. While we will see little net job creation from demand effects in the model, these sectors along with the ICT sectors are those where the positive demand effects are strongest for a given decline in ICT user cost.

Figure 42 summarises the total elasticity of labour demand with respect to ICT user cost, adding up substitution and demand effects. We see that it falls below 0.1 in most sectors. In many sectors it is in the range of 0.02. An elasticity of 0.02 means that a reduction in ICT user cost by 10 percent reduces labour demand by 0.2 percent. We do not see any positive average elasticity over the years 2000-2021, though some values are very close to zero. High elasticities are found in Information and Communication (J) and Finance (K). Medium values are observed in the goods-producing sectors except Construction (F) and Agriculture (A). Figure 42 adds three pieces of information: (1) It splits substitution and demand effects, (2) it adds TFP effects in the ICT sector not included in the previous figure and (3) it multiplies the elasticities with the predicted decline in user cost to show employment change due to digitisation predicted by the model. Employment change is displayed in relative terms. Country differences partly reflect differences in user cost decline (see Figure 37). It is also obvious that positive demand effects are stronger the stronger the negative substitution effects are. This is because both depend on the output elasticity. To put it simply, both the risks of job creation and the chances of stimulating additional demand are higher in sectors and countries where digitisation is already important. This is reflected in a common factor in the cost model. Unless you are able to drastically alter the substitution and demand elasticities, it is not possible to increase one effect without the other. These counteracting effects also highlight that a low net employment change may hide substitution between different categories of workers, since processes are rearranged and production is scaled up with these different processes. Results on different skill groups (OECD, 2016) support this idea, though it cannot be investigated further in the context of the present project.

We see that substitution and demand effects are very low in Agriculture (A) and Construction (F). In many other sectors we observe medium effects with absolute values between 0.2 and 0.5 percent per year. Substitution effects are higher in Electricity, Gas and Water Supply (D_E) and Finance (K), with Japan as an outlier. The sector Information and Communication (J) shows both high substitution and high demand effects, which are amplified by the TFP effects. In the Production of Electrical and Optical Equipment (26_27), we see medium substitution effects and very high TFP effects.

Overall, net annual job loss from digitisation is far below one percent in many sectors. While the sectoral pattern differs, the overall magnitude is in line with the findings of the OECD (2016). We do not find net positive effects except when also considering ICT-related TFP. But demand effects clearly counteract the substitution of labour.

Finally, Figure 43 summarises employment effects in absolute numbers. These are aggregated for four regions in Figure 44 and compared to actual employment change. In China, more than 40 million jobs are predicted to be created between 2000 and 2021 with slightly less than 20 million due to digitisation. This positive effect is the result of TFP growth in the production of electrical and optical equipment. Actual net job creation between 2000 and 2014 has obviously taken place for reasons that we cannot attribute to digitisation in this analysis (see Figure 14). In the US, we see a small positive effect of digitisation on overall employment, which can be interpreted in a similar way to the trend in China. The effects of digitisation in the EU15 region and in Japan can be considered neutral when compared to actual employment change. Of course this again hinges on the TFP effect, which is modelled in a fairly rough way.

We have to repeat the caveat that the way TFP is included in the analysis is very rudimentary. TFP growth in the ICT sectors may reflect technical change that is in part not neutral but factor-biased. However, our data set, like most macroeconomic data, does not permit the identification of this factor bias from a production function. In reality, employment might not rise one-to-one with TFP-related demand increases. On the other hand, we have not attributed any TFP growth in the other sectors to digitisation. At the aggregate level, the overall error from this simplification will be smaller than at the sectoral level.

A sensitivity analysis has been carried out assuming that TFP growth is to some extent labour-saving, which means that it increases labour demand less than one-to-one. More precisely, we assume only half of TFP growth to be labour-augmenting (which in view of the analysis by Autor and Salomons (2017) might be rather an upper than a lower bound). On the other side, we assume in this sensitivity analysis that not only TFP growth in the ICT-producing sector but also some TFP growth in the other sectors is reflecting increasing digitisation. The share of TFP growth related to digitisation is assumed to correspond to the ratio of the ICT output elasticity to the output elasticity of total capital. The detailed numerical results are not reported. The aggregate employment effect resulting from this exercise is close to zero in the EU and the US, similarly to the effect in the main specification of this study, and negative in Japan. Compared with the main model, sectoral effects are generally less positive in the ICT-producing sector and less negative or even slightly positive in the other sectors. A more rigorous analysis along these lines could be undertaken in future research.

Since the exact computation of standard errors is problematic in our estimation of production functions, we report as part of an additional sensitivity check (included in the appendix) numbers which rely on the assumption of an elasticity of substitution of one in all sectors and countries. This lowers substitution effects in most sectors and leads on average to modest employment gains in most countries. For example, for the EU15 our results under this assumption imply an additional of 2 million jobs, which, of course, is still a small effect given the time period and the size of the population. We consider this exercise as a robustness check which illustrates how strongly our results depend on key assumptions and which shows that our finding of more or less neutral employment effects overall due to ICT hold given alternative assumptions.

5.3. Different scenarios

Sectors with low, medium and high elasticity of labour demand to ICT user cost

In order to consider different scenarios implied by the model, we consider how strongly labour demand reacts to a decline in ICT user cost in different sectors (Figure 42, excluding TFP effects). This effect is very high in Information and Communication (J) and Finance (K). It is medium in manufacturing and low to very low in other services, Agriculture and Construction. These differences are in our view the three main sectoral scenarios highlighted by our study. For the sectors with very low effects, we also see the strongest contrast in demand elasticities, which are low in Agriculture, medium in Construction and high in Education and Health and Social Work.

In the sectors with low employment effects, the level of ICT capital services is generally also low. In these sectors, the numbers point to chances of digitisation that are so far largely unexploited and to job losses from further digitisation that would still be low. This applies to digitisation measured by ICT capital services and ignores additional TFP effects of digitisation that are not directly correlated to the overall level of ICT capital services in the sector. In the sectors with low effects, the demand elasticities are fairly heterogeneous, which is not visible from the small magnitude overall. But with further digitisation, it may be difficult to prevent stronger job losses in Agriculture (A), where demand effects are very low, and easier to prevent them in Education (P) and Health and Social Work (Q) where demand effects are higher. We observe a similar contrast for the two service sectors with high substitution effects by ICT capital: demand elasticities are low for Finance (K) and medium-to-high for Information and Communication (J). The picture in the latter sector, is, however, dominated by the added TFP effect.

In the manufacturing sectors with medium overall effects of digitisation and in Electricity, Gas and Water Supply, both the ICT share and the elasticity of substitution are higher than in the first group of sectors and this higher negative effect is not matched by systematically higher demand elasticities. In these sectors, productivity effects from further digitisation are higher than in the first group but net job loss is also higher. In the highly ICT-intensive services Information and Communication (J) and Finance (K), we would expect the largest job loss from further ICT investment (ignoring the TFP effect in J).

What these different sectoral scenarios mean at the country level also depends on the sectoral composition of the country. In Figure 43, we see that aggregate job creation resulting from digitisation is positive in most countries when taking into account the TFP effects in the ICT sector. It is, however, negative in UK and Spain and close to zero in Germany, Japan and the Netherlands. Predicted job loss in Spain mainly results from the country's large trade sector and from very limited TFP growth in the Information and Communication sector (J). The pattern looks similar in the Netherlands, where TFP growth is higher in sector J but negative in the Production of Electrical and Optical Equipment (26_27). In Japan, the negative effects in the Information and Communication (J) and the Finance sector (K) stand out. When looking at the US and the EU15, the 0.5 to around 1 million jobs substituted by ICT in Trade (G) in each of these regions reveal a medium-sized relative effect that is amplified by the size of the sector and may thus also receive more public attention than e.g. job substitution in the Electricity, Gas and Water Supply (D_E).

5.4. Future research

We have several suggestions for future research:

- This study has highlighted a number of methodological difficulties (determining whether an elasticity of substitution is significantly higher than one, estimating a sectoral demand system that is consistent with aggregate demand and that includes both final and intermediate demand, estimating cross-price effects in a rigorous way) that would be worthwhile addressing with a data set that covers less countries but a longer time span. Maybe some of the analysis could even be undertaken for a single country for which high-quality data are available.

- Previous empirical research on relating TFP to digitisation has been inconclusive (see Cardona et al., 2013) though intuition suggests that digital innovation reflected in TFP rather than in ICT capital services will play a growing role. Perhaps applied modelling combining micro and macro insights and exploring alternative assumptions can deliver more insights than a primarily econometric evaluation of production functions.
- Future applied research on the employment effect of digitisation should also address the role of intangible investment that is complementary to ICT, such as organizational investment.
- Our analysis as well as that by the OECD suggests fairly moderate job losses due to digitisation while the literature on skill content suggests higher job losses in the future. Applied modelling should go further in combining those two strands of literature.

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7. APPENDIX

Table 2: Estimation NACE 1.1 / ISIC 3.1 based data

	Value added	Labour (hours)	ICT cap. services	Non-ICT capital services	Wage (labour compensation)	ICT user costs	Non-ICT user costs	Value added deflator
USA	1995-2007	1995-2007	1995-2007	1995-2007	1995-2007	1995-2007	1995-2007	1995-2007
China	1995-2007	1995-2007	1995-2007	1995-2007	1995-2007	1995-2007	1995-2007	1995-2007
Japan	1995-2005	1995-2005	1995-2005	1995-2005	1995-2005	1995-2005	1995-2005	1995-2005
Germany	1995-2007	1995-2007	1995-2007	1995-2007	1995-2007	1995-2007	1995-2007	1995-2007
UK	1995-2007	1995-2007	1995-2007	1995-2007	1995-2007	1995-2007	1995-2007	1995-2007
France	1995-2007	1995-2007	1995-2007	1995-2007	1995-2007	1995-2007	1995-2007	1995-2007
Italy	1995-2007	1995-2007	1995-2007	1995-2007	1995-2007	1995-2007	1995-2007	1995-2007
Spain	1995-2007	1995-2007	1995-2007	1995-2007	1995-2007	1995-2007	1995-2007	1995-2007
Netherlands	1995-2007	1995-2007	1995-2007	1995-2007	1995-2007	1995-2007	1995-2007	1995-2007
Sweden	1995-2007	1995-2007	1995-2007	1995-2007	1995-2007	1995-2007	1995-2007	1995-2007
Austria	1995-2007	1995-2007	1995-2007	1995-2007	1995-2007	1995-2007	1995-2007	1995-2007
Finland	1995-2007	1995-2007	1995-2007	1995-2007	1995-2007	1995-2007	1995-2007	1995-2007

WIOD Socio Economic Accounts Release July 2014	EU KLEMS database (November 2009 Release)
WIOD Socio Economic Accounts Release July 2014/EU KLEMS database (November 2009 Release)	EU KLEMS database (March 2008 Release)

Table 3: Projection NACE 2 / ISIC 4 based data

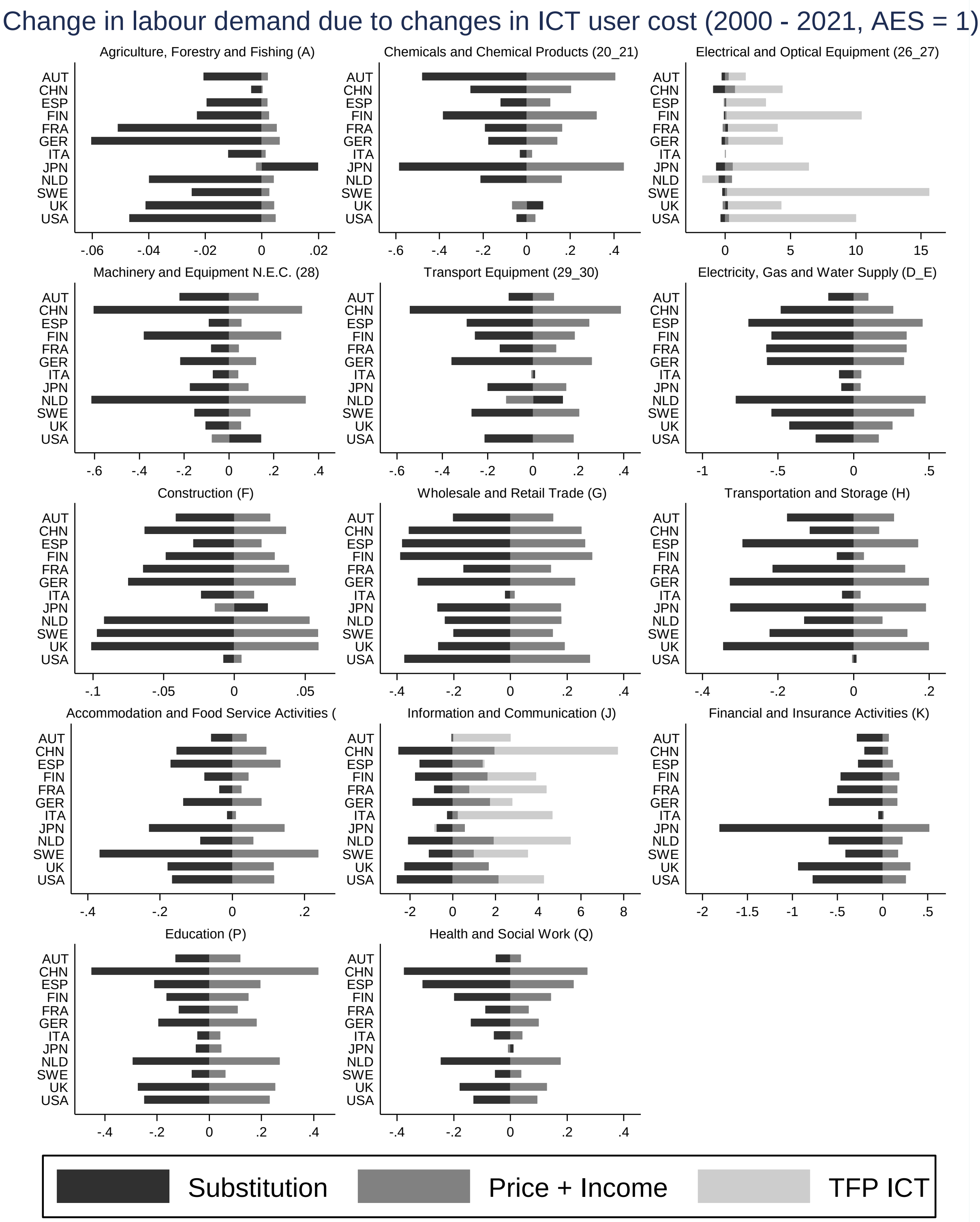
	Value added	Labour (hours)	ICT cap. services	Non-ICT capital services	Wage (labour compensation)	ICT user costs	Non-ICT user costs	Value added deflator
USA	2000-2014	2000-2014	2000-2014*	2000-2014*	2000-2014	2000-2014*	2000-2014*	2000-2014
China	2000-2009	2000-2009	2000-2009	2000-2009	2000-2009	2000-2009	2000-2009	2000-2009
Japan	2000-2009/10-14	2000-2009	2000-2009	2000-2009	2000-2009	2000-2009	2000-2009	2000-2009
Germany	2000-2014	2000-2014	2000-2014*	2000-2014*	2000-2014	2000-2014*	2000-2014*	2000-2014
UK	2000-2014	2000-2014	2000-2014*	2000-2014*	2000-2014	2000-2014*	2000-2014*	2000-2014
France	2000-2014	2000-2014	2000-2014*	2000-2014*	2000-2014	2000-2014*	2000-2014*	2000-2014
Italy	2000-2014	2000-2014	2000-2014*	2000-2014*	2000-2014	2000-2014*	2000-2014*	2000-2014
Spain	2000-2014	2000-2014	2000-2014*	2000-2014*	2000-2014	2000-2014*	2000-2014*	2000-2014
Netherlands	2000-2014	2000-2014	2000-2014*	2000-2014*	2000-2014	2000-2014*	2000-2014*	2000-2014
Sweden	2000-2014	2000-2014	2000-2014*	2000-2014*	2000-2014	2000-2014*	2000-2014*	2000-2014
Austria	2000-2014	2000-2014	2000-2014*	2000-2014*	2000-2014	2000-2014*	2000-2014*	2000-2014
Finland	2000-2014	2000-2014	2000-2014*	2000-2014*	2000-2014	2000-2014*	2000-2014*	2000-2014

OECD Annual National Accounts, *own calculation

EU KLEMS "statistical module", December 2016 revision *own calculation

EU KLEMS 2012 Release; forecast for 2010-2014 based on industry level value added from OECD NA

Based on NACE 1 WIOD Socio Economic Accounts Release July 2014/EU KLEMS database (November 2009 Release); forecast after 2009



Notes: Results show average annual percentage changes in labour demand. TFP-effects are included in industries 26_27 and J.

Figure 45: Change in labour demand due to changes in ICT user cost under the assumption of an AES = 1 in all sectors (split into substitution-, price+income-, and TFP-effect), in percent (2000 - 2021)

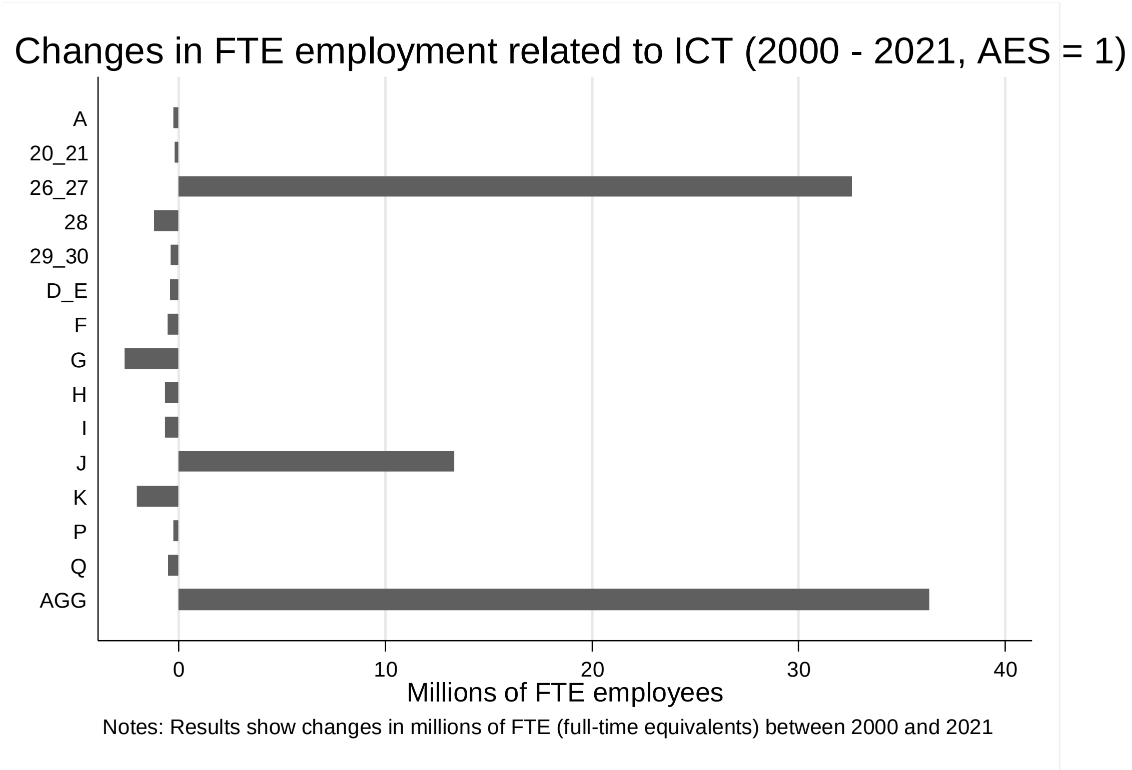


Figure 46: Changes in employment related to ICT under the assumption of an AES = 1 in all sectors (between 2000 and 2021) in millions of FTE

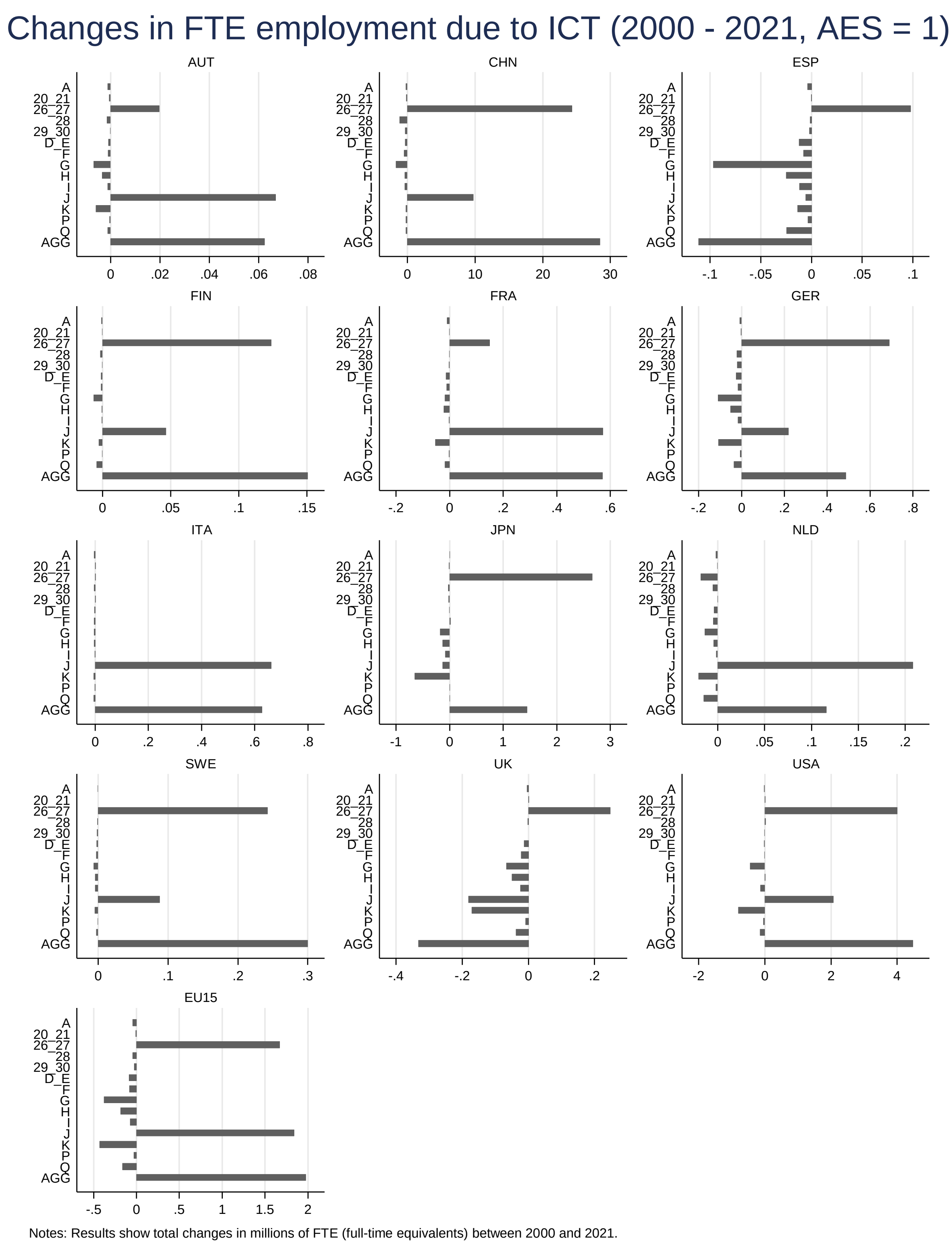


Figure 47: Changes in FTE employment due to ICT under the assumption of an AES = 1 in all sectors (2000 - 2021)

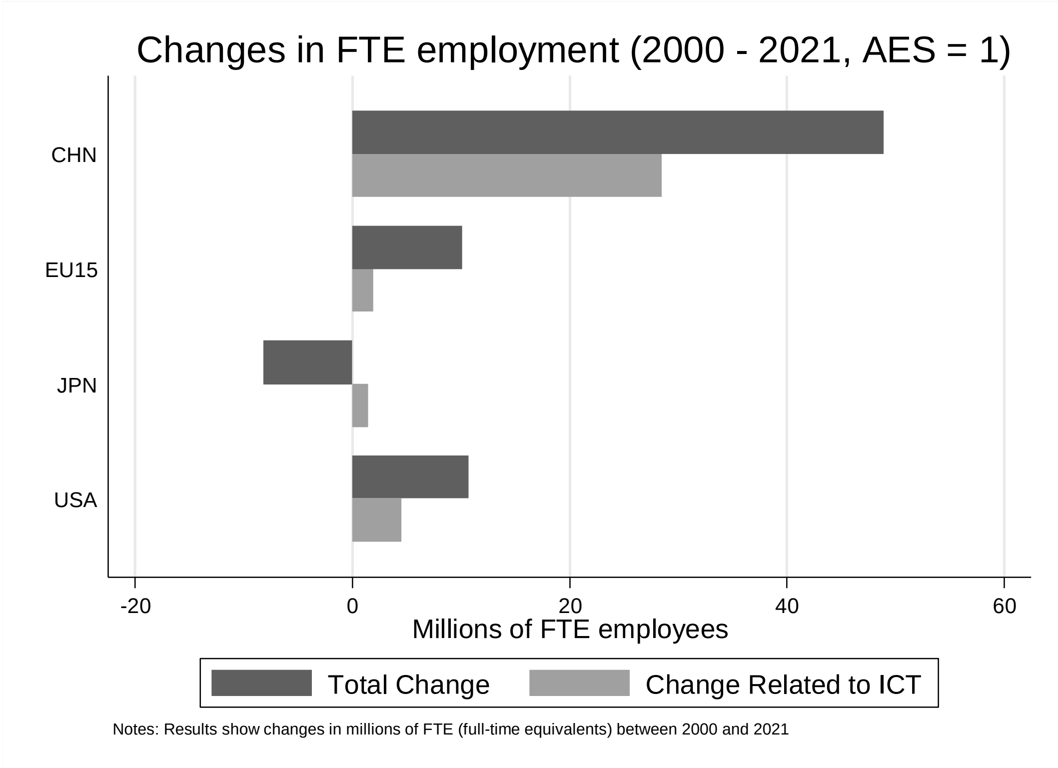


Figure 48: Total changes in employment and changes in employment related to ICT under the assumption of an AES = 1 in all sectors (2000 – 2021) in millions of FTE

European Commission

The Sectoral Impact of the Digitisation of the Economy
Luxembourg, Publications Office of the European Union

85 pages

ISBN number
DOI: number

DOI: number

ISBN number