European Commission

JRC Technical Report

ICT specialists in employment

Methodological note

JRC Working Papers Series on
Labour, Education and Technology
2020/07

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LABOUR EDUCATION TECHNOLOGY

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EU Science Hub
https://ec.europa.eu/jrc

JRC119846

Seville: European Commission, 2020

How to cite this report: López Cobo M., Rohman I.K., De Prato G., Cardona M., Righi R., Samoili S., Vázquez-Prada Baillet M., *ICT specialists in employment.. Methodological note*, Seville: European Commission, 2020, JRC119846.

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Abstract

The digital transformation of the economy and society has intensified the need for digitally skilled labour force. Recent studies inform about expected increased demand, and skill shortages in the Information and Communication Technologies (ICT) sector, with a widening gap between supply and demand of ICT specialists. The need for accurate data on the number of ICT specialists in employment becomes more pertinent due to the development of policy initiatives aimed at increasing digital skills.

Eurostat and the OECD define ICT specialists and propose a statistical definition using the International Standard Classification of Occupations (ISCO) 2008. Based on the Labour Force Survey, Eurostat provides an estimated 8.9 million persons working as ICT specialists in 2018 in the EU. This indicator annually feeds the Digital Economy and Society Indicator, a composite indicator that assesses the digital performance of EU Member States.

This paper shows that this value underestimates the actual number of ICT specialists and proposes a more accurate method for the estimation. The list of ICT occupations includes both 3-digit (3d) and 4-digit (4d) codes. The number of EU Member States not reporting 4d data was 12 in 2011 and 6 in 2018. Therefore, the direct implementation of the definition is not possible, and a method is needed to estimate the missing 4d values and produce complete estimates for the EU. Eurostat developed an estimation method based on education data (EF method) to provide estimates for ICT in employment. This paper proposes the Ratio method for the estimation of missing data, compares its performance with the EF method, and produces estimates on ICT specialists in employment for 2004-2018, for the EU and its Member States.

The results show that the Ratio method provides more accurate estimates than the EF method. We test the performance with two error measures by means of a cross-validation algorithm; in both cases, all six variants of the Ratio method tested reduce the error of the EF method between 35% and 55% when measured on countries reporting 4d data. The new proposed method estimates 9.2 million ICT specialists are working in the EU in 2018, 2% above the value with the old estimation method (the difference reached 26% in 2004). At country level, for countries with missing data, the new method implies an average increase of 34% in 2004-2010 and 17% in 2011-2018 with respect to the estimate with the current method. According to our estimations, the number of ICT specialists in employment followed an increasing trend over the two analysed periods (2004-2010 and 2011-2018), with an overall increase of 19% in the first period, and of 35% in the second one. The share over total employment also increases, with a grow from 3.2% in 2011 to 4.0% in 2018. These results are in line with other studies that show that the ICT sector was more resilient to the economic crisis that started in 2008 than the whole economy.

Keywords: ICT specialists, employment, estimation, error measure, cross-validation

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Acknowledgements: The authors would like to acknowledge Ales Capek, Michaela Grell, Carsten Olsson (DG ESTAT) and Paul Desruelle (JRC) for their support. We acknowledge the useful comments made by Roger Gomis (ILO), Nathalie Schueller (DG ESTAT) and Sergio Torrejón Pérez (JRC), that helped improve the report. We are indebted to Anna Sabadash, Frank Bauer and the ESTAT LFS User Support Team (DG ESTAT) for the invaluable collaboration in the development process of this work. We also acknowledge Andrea De Panizza for his participation in the initial stages of this research.

Joint Research Centre reference number: JRC119846

Contents

Introduction

Policy context and measuring efforts

The digital transformation of the economy and society has intensified the need for digitally skilled labour force. Recent studies inform about: (i) expected increased needs for certain IT specialists' occupations (software and application developers), (ii) genuine skill shortages in the ICT sector (Cedefop, 2015), and (iii) lack of professionals with advanced digital skills (e.g. ICT security, cloud computing) (European Commission, 2012b).

Both the number of ICT specialists in employment and its proportion over all labour force both follow an increasing path since at least 2012. Nevertheless, the proportion of ICT graduates over all graduates stays stationary, and a growing proportion of enterprises state having difficulties in filling ICT specialists' vacancies (European Commission, 2019a, 2019b). Additionally, the digital revolution is at the root of the arrival of new forms of employment, including ICT-based mobile work or other digitally enabled jobs (Gonzalez Vazquez et al., 2019). All this evidence suggests a widening gap between supply and demand of ICT specialists. There is a clear need for further upskilling and re-skilling European labour force in order to reduce digital skills gaps (European Commission, 2019a), and to fully benefit from advanced digital technologies, such as artificial intelligence, block chain or supercomputing, to mention a few.

While initiatives aimed at increasing digital skills develop -such as the Digital Skills and Jobs Coalition-, the need for accurate data on the number of ICT specialists in employment becomes more pertinent. Several studies and official statistics cover this information area. Cedefop's *Skills Panorama's analytical highlights on ICT professionals*[1] (Cedefop, 2019a) analyses the evolution of ICT professionals between 2006 and 2018, and projects a growth of another 11% between 2018 and 2030. Similarly, the *Skills Panorama's analytical highlights on ICT technicians*[2] (Cedefop, 2019b) provides a projection of future employment growth by a further 5% between 2018 and 2030 for ICT technicians.

However, Cedefop only considers these two occupation groups, ignoring other occupations that are also considered ICT occupations. Eurostat and the Organisation for Economic Co-operation and Development (OECD) define ICT specialists as "workers who have the ability to develop, operate and maintain ICT systems, and for whom ICT constitute the main part of their job" (OECD, 2015) and propose a statistical definition of ICT specialists based on the International Standards Classification of Occupations (ISCO) 2008, following the International Labour Organization recommendation (ILO, 2012) and OECD (2013). The statistical definition of ICT specialists is based on occupations following the ISCO. ISCO-88 is until 2010, whereas ISCO-08 is applied from 2011 to the latest available year. Table 1 presents the list of ICT occupations under ISCO-88 and Table 2 does for ISCO-08[3].

[1] This corresponds to the ISCO submajor group 25 (Information and Communications Technology Professionals).

[2] This corresponds to the ISCO submajor group 35 (Information and Communications Technicians).

[3] The use of the classification of occupations introduces a break in the series in 2011 due to the absence of one-to-one correspondence between ISCO-88 and ISCO-08 on the 3d and 4d levels of aggregation. This means that: (i) two separate ISCO-based definitions corresponding to two sub-periods, prior to 2010 and from 2011 onwards, need to be used to estimate ICT specialists, and (ii) the break in the series impedes comparability of data referred to before and after 2011 (Eurostat, 2016).

In an attempt to estimate ICT specialists' employment trends, the OECD applies a simplification of the referred definition, by removing the 4d ISCO codes from the definition[4] (OECD, 2017). Only Eurostat provides estimates according to the full definition, covering also the seven 4d ISCO-88 occupations and the eight 4d ISCO-08 occupations[5], and provides an estimated 8.9 million persons working as ICT specialists in 2018 in the EU, accounting for 3.9% of the total workforce in that year (Eurostat, 2019).

Table 1. ICT occupations in ISCO-88 (until 2010)

ISCO code	Occupation name
1236	Computing services managers
213	Computing professionals
2144	Electronics and telecommunications engineers
2359	Information technology trainers
3114	Electronics and telecommunications engineering technicians
312	Computer associate professionals
313	Optical and electronics equipment operators
7242	Electronics fitters
7243	Electronics mechanics and servicers
8283	Electronic-equipment assemblers

Source: Eurostat (2016)

Table 2. ICT occupations in ISCO-08 (since 2011)

ISCO code	Occupation name
I. ICT managers, professionals and associate professionals	
133	ICT Service managers
25	*Information and communications technology professionals*
251	Software and multimedia developers and analysts
2511	Systems analysts
2512	Software developers
2513	Web and multimedia developers
2514	Application programmers
2519	Software and multimedia developers and analysts not elsewhere classified
252	Database specialists and systems administrators

[4] ICT specialists are defined as those individuals employed in "tasks related to developing, maintaining and operating ICT systems and where ICTs are the main part of their job". Based on the operational definition based on ISCO-08 3d which includes occupations: 133, 215, 25, 35, 742.

[5] The 4-digit codes of ISCO-08 in the submajor groups 25 and 35 do not need to be estimated, because the employment values corresponding to the whole submajor groups are provided by all countries.

ISCO code	Occupation name
2521	Database designers and administrators
2522	Systems administrators
2523	Computer network professionals
2529	Database and network professionals not elsewhere classified
35	*Information and communications technicians*
351	ICT operations and user support technicians
3511	ICT operations technicians
3512	ICT user support technicians
3513	Computer network and systems technicians
3514	Web technicians
352	Communications technicians
3521	Broadcasting and audio-visual technicians
3522	Telecommunications engineering technicians
II. Other unit groups that primarily involve the production of ICT goods and services	
2152	Electronic engineers
2153	Telecommunication engineers
2166	Graphic and multimedia designers
2356	Information technology trainers
2434	ICT sales professionals
3114	Electronics engineering technicians
7421	Electronics mechanics and servicers
7422	ICT installers and servicers

Source: OECD (2015)

Challenges in the implementation of the definition of ICT specialists

The list of ICT specialists' occupations includes 2-digit, 3d and 4d codes. Although the estimate is not provided at this level of detail, employment in 4d codes whose parent 2-digit or 3d code is not fully covered by the definition need to be estimated individually. This affects to the following ISCO codes: *1236, 2144, 2359, 3114, 7242, 7243, 8283* for ISCO-88 and *2152, 2153, 2166, 2356, 2434, 3114* for ISCO-08[6]. In this work, when referring to 4d codes, we constrain to consider only these occupations whose parent occupations are not covered by the definition. Until 2011, 12 EU Member States did not report data on occupations at 4d level (Table 3). In 2018, six countries still did not provide such data. Therefore, the direct implementation of the definition is not possible in those cases and a method to estimate the missing 4d values has been put in place in order to publish complete estimates for all the countries. Eurostat developed a method to estimate missing

6 Occupations 7421 and 7422 are also part of the ICT specialists' occupation list under ISCO-08, but as they are the only 4d codes in the parent 742, there is no need to estimate individually these occupations; instead, employment in the 3d group is taken in its entirety.

data for countries not providing employment figures for 4d codes, which is currently being used to provide estimates for ICT in employment as published by Eurostat (Eurostat, 2019).

This report proposes an alternative method for the estimation of missing data in an attempt to provide more accurate estimates for the countries not providing the information needed to apply the definition of ICT specialists. Furthermore, the proposed method has the advantage of being easy to implement, which would facilitate its future adoption by Eurostat. This work describes the proposed method, compares its performance with that of the method used by Eurostat, and produces estimates on ICT specialists in employment in the period 2004-2018, for the EU and its Member States. The results show that the proposed method provides more accurate estimates than the method currently in use.

This research takes place in the context of the PREDICT project, which produces statistics and analyses on the ICT sector and its R&D[7]. In order to capture how the ICTs are embedded in other sectors of the economy, since 2017 PREDICT is broadening its scope to cover ICT content in other economic activities, trade in ICT assets and ICT in employment. This report focuses on the estimation of ICT specialists in employment.

Table 3. EU Member States reporting 4d data by the first reporting year in the period 2004-2018

2006	**2011**	**2012**	**2015**	**2017**	**not yet available**
CZ	IE*	BE	CY	IT	BG
EE	FR*	DE			DK
HR					EL
LT					ES
LU					LV
HU					PT
MT*					
NL*					
AT					
PL					
RO					
SI					
SK					
FI					
SE					
UK*					

Note: Countries with asterisk have missing data in some 4d occupations for the period in which they report 4d data.

7 PREDICT, "Prospective Insights in ICT R&D", is a collaboration between the JRC and the European Commission Communications Networks, Content and Technology (CNECT) Directorate General. PREDICT produces statistics and analyses on Information and Communication Technology (ICT) industries and their R&D in Europe since 2006. The project covers major world competitors including 40 advanced and emerging countries – the EU28 plus Norway, Russia and Switzerland in Europe, Canada, the United States and Brazil in the Americas, China, India, Japan, Korea and Taiwan in Asia, and Australia – as well as a growing array of indicators related to the ICT content of economic activities. PREDICT provides indicators in a wide variety of topics, including value added, employment, labour productivity and BERD, distinguishing fine grain economic activities in ICT and media and content industries. The PREDICT Dataset is based on the latest data available from official sources (such as the Eurostat and OECD, National Accounts and R&D statistics).

Several countries do not provide data for some 4d occupations during their reporting period (countries with asterisk in Table 3). Several reasons may explain this circumstance (e.g. no sample units reported this occupation, mismatch between ISCO and national classifications impede to provide the values at 4-digit level). Just like Eurostat does in the computation, we take zero as the actual value in these cases, to avoid estimating these missing values[8].

Description of the estimation methods

Eurostat´s Education Filter method and its limitations

The method developed and used by Eurostat, the Education filter (EF) method, relies on a combination of occupations and education taxonomies to impute missing values. In particular, it uses the level of attained education of the respondent –also available in the Labour Force survey- to proxy ICT 4d occupations in the wider 3d parent group. In order to estimate figures for the 4d occupations, the EF method takes the number of workers in the parent 3d occupation, and considers only workers with an ICT-related attained education level[9] (Eurostat, 2016).

The EF method is found to underestimate the actual values of ICT specialists. Table 4 shows, for occupation *2166* (Graphic and multimedia designers) and year 2018, the comparison between the actual values for countries reporting employment in 4d occupations and the estimates that would result if the EF method was applied to those countries.

We can observe over that the EF method heavily underestimates the values in all countries. The degree of underestimation is quite high for all countries, ranging from 66% to 100%, with most countries underestimated by more than 90%. This underestimation is also observed in other occupations and years (see Annex).

[8] If the actual value was different from zero, there would be two related consequences: the underestimation of employment in these countries, and the underestimation of employment in countries with missing data and for which these data are used.

[9] ICT-specific education is captured in the International Standard Classification of Education Fields of Education and Training 2013 (ISCED-F) by the category 06 Information and Communication Technologies, which covers all types of education related to Computer use (0611), Database and network design and administration (0612), and Software and applications development and analysis (0613). Code 06 under ISCED-F 2013 corresponds to code 48 Computing under ISCED 1997 Fields of education, comprising Computer system design, computer programming, data processing, networks, and operating systems dealing with software development (those related to the hardware development are classified within the engineering fields). This group comprises two sub-groups: Computer sciences (481), and Computer use (482).

Table 4. Actual versus estimated employment (EF method) for occupation 2166 "Graphic and multimedia designers" (thousand persons), 2018

	Actual value for occupation 2166 (A)	**Estimated value for occupation 2166 (EF method) (B)**	**Error**	
			Absolute (B-A)	**% (B-A)/A**
Belgium	15.5	0	-15.5	-100%
Czechia	4.9	0.5	-4.4	-90%
Germany	124.3	5.6	-118.7	-95%
Estonia	2.1	0	-2	-98%
Ireland	3.4	0	-3.4	-100%
France	79.6	2.4	-77.2	-97%
Croatia	1.7	0.6	-1.1	-66%
Italy	53.9	1.7	-52.2	-97%
Cyprus	0.9	0	-0.9	-100%
Lithuania	1.4	0.3	-1.1	-78%
Luxembourg	1.3	0.1	-1.2	-89%
Hungary	7.9	0.2	-7.7	-98%
Malta	1	0	-1	-100%
Netherlands	43.1	2.2	-40.9	-95%
Austria	19.4	0.5	-18.9	-97%
Poland	41.1	9.7	-31.4	-76%
Romania	*c*	*c*	*c*	-93%
Slovenia	3.2	0.1	-3.1	-98%
Slovakia	5.3	0.1	-5.2	-99%
Finland	7	0.5	-6.5	-92%
Sweden	19.9	1.3	-18.6	-93%
United Kingdom	93.3	1.8	-91.4	-98%

Notes: The table includes the 22 countries reporting data for occupation 2166 in 2018. ‘c’: confidential data.

Source: JRC estimation and Eurostat.

The Ratio method

As an alternative to the Eurostat method, this work presents the Ratio method in an attempt to provide more accurate estimates for the countries not providing the detailed 4d data needed to apply the definition of ICT specialists.

The main characteristic of the Ratio method is that it relies on actual information from the countries that provide employment at 4d level (Table 3). For those countries, and for each 4d ISCO code, we compute the proportion or ratio of the number of workers in the 4d occupation over the number of workers in the parent 3d occupation. These ratios are summarised to compute an overall ratio per occupation. Considering different computation formulas, we develop six different variants that are tested in the following section. The selected ratio is then used to estimate employment in the 4d occupations for countries with missing data, by multiplying the ratio by the number of workers in the parent 3d occupation.

Due to the introduction of the ISCO revision in 2011, comparability over time is severely impacted, since there is not a one-to-one correspondence of ICT occupations between ISCO-88 and ISCO-08. Therefore, two different lists of ICT occupations must be used: one for the period 2004 to 2010 (Table 1); another one for 2011 onwards (Table 2). Consequently, the method is applied independently to the two periods and the results show a clear series break, most probably due to unequal coverage of ICT employment by the two lists of occupations. The method is described in detail in this section. For each 4d ISCO code in each time period we follow a three step process:

Step 1. Identify missing values at 4d level

The dataset is split into two subsets: (1) observations corresponding to country-year pairs with missing values, and (2) observations corresponding to country-year pairs without missing values. The criterion to split the dataset is the country and year, in accordance with Table 3. As a consequence, countries providing 4d data from a certain year onwards are considered as providing 4d data for all 4d codes and all following years, and any missing value is considered as a zero estimate, i.e., no cases found in the sample. The rationale is to avoid the possibility of wrongly interpreting as missing values the absence of observations in a specific occupation in countries that report 4d values.

Step 2. Impute 4d data

Step 2.1. Countries where all years in the period are missing

As mentioned, the estimation of ICT specialists is computed independently for the two periods 2004-2010 and 2011-2018. We compute the ratio using data from the countries reporting 4d data for at least one year[10], this ratio is then applied to all countries with missing 4d data in the whole period.

We have tested six alternative ratios following different formulas to aggregate country data. The ratios are computed for each occupation independently. Ratios r_1 to r_4 are single numeric values that are used for all countries and years. Ratios r_5 and r_6 are vector-ratios with a value per year. The latter are expected to capture changes over time and hence to better reflect the trend of the indicator we aim at measuring. They are convenient for practical reasons too, since the ratio can be updated every year with the new available data and the whole time series does not need to be recomputed.

[10] Here we also consider the countries providing 4d data for some years, e.g. Belgium, Germany (since 2012).

Notation used in the formulas:

O_{ICT}	List of 4d occupations considered as ICT: {1236, 2144, 2359, 3114, 7242, 7243, 8283} for ISCO-88; {2152, 2153, 2166, 2356, 2434, 3114} for ISCO-08.
$E_{c,t}^{o_{4d}}$	Value of employment (thousand persons) in the 4d occupation o, country c and year t
$E_{c,t}^{o_{3d}}$	Value of employment in the parent 3d group of the 4d occupation o in country c and year t
T^o	Set of years for which occupation o must be reported: {2004, …, 2010} for o ∈ ISCO-88 and {2011, …, 2018} for o ∈ ISCO-08
T_c^o	Set of years for which occupation o is reported in country c
$C_{4d,t}^o$	Set of countries reporting 4d data for year t in occupation o
C_m^o	Set of countries with missing 4d data for all years in T^o
n_t^o	$n(C_{4d,t}^o)$: number of countries reporting 4d data for year t in occupation o
m^o	$n(T^o)$: number of years of the period on which occupation o must be reported

Single-value ratios

r_1: Overall single ratio

The ratio r_1 is computed as the sum of non-missing 4d values in all countries and years divided by the sum of their parent 3d values. By construction, this ratio gives more weight to countries with higher employment levels, such as United Kingdom, France or Germany and, consequently, the value of this overall ratio greatly depends on the number of ICT specialists in those countries.

[1] $$r_1^o = \frac{\sum_{c,t} E_{c,t}^{o_{4d}}}{\sum_{c,t} E_{c,t}^{o_{3d}}} \qquad \text{for } c \in C_{4d,t}^o,\ t \in T^o,\ o \in O_{ICT}$$

r_2: Mean of country-year ratios

For r_2, we first compute one ratio per country-year pair, and then the ratios are averaged with an arithmetic mean over number of years and countries. This ratio concedes equal importance to all countries and all years. Consequently, it smooths the impact of country outliers, since every country-year pair is reduced to its ratio value before averaging, and ratios have a lower variance than the absolute values of the numerators and denominators used for the ratios' computation.

[2] $$r_2^o = \frac{\sum_{c,t} \frac{E_{c,t}^{o_{4d}}}{E_{c,t}^{o_{3d}}}}{\sum_t n_t^o} \qquad \text{for } c \in C_{4d,t}^o,\ t \in T^o,\ o \in O_{ICT}$$

r_3: Mean of country-ratios

For each country we compute a single overall country-ratio, as in r_1 but limited to each country, i.e., as the sum of non-missing 4d values in the country divided by the sum of their parent 3d values. In a second step, we average all the country-ratios with an arithmetic mean over number of countries. The individual country-ratios computed in the first step are, just like r_1 is, sensitive to countries with highest employment levels. This limitation is softened in the second step in which the final ratio is defined as the arithmetic mean on the country-ratios.

[3] $$r_3^o = \frac{\sum_c \frac{\sum_{t'} E_{c,t'}^{o_{4d}}}{\sum_{t'} E_{c,t'}^{o_{3d}}}}{\max_t \{n_t^o\}} \qquad \text{for } c \in C_{4d,t}^o,\ t' \in T_c^o,\ t \in T^o,\ o \in O_{ICT}$$

r4: Mean of year-ratios

Defined in a similar way as r_3, but exchanging the dimension *country* for the dimension *year*. We first compute a single overall year-ratio, as the sum of the 4d values in all countries for the selected year divided by the sum of their parent 3d values. Then, the year-ratios are averaged with an arithmetic mean over number of years.

[4] $$r_4^o = \frac{\sum_t \frac{\sum_c E_{c,t}^{o_{4d}}}{\sum_c E_{c,t}^{o_{3d}}}}{m^o} \qquad \text{for } c \in C_{4d,t}^o,\ t \in T^o,\ o \in O_{ICT}$$

Vector ratios

r5: Vector of means of country-ratios per year

For each year of the period, we compute one ratio per country, which is then averaged with an arithmetic mean over number of reporting countries. Therefore, r_5 is a vector of year-ratios $\{r_{5,t}^o\ , t \in T^o\}$, and can be seen as a time-dimensional version of r_2. As such, it smooths the impact of country outliers.

[5] $$r_{5,t\in T^o}^o = \frac{\sum_c \frac{E_{c,t}^{o_{4d}}}{E_{c,t}^{o_{3d}}}}{n_t^o} \qquad \text{for } c \in C_{4d,t}^o,\ t \in T^o,\ o \in O_{ICT}$$

r6: Vector of overall single ratios per year

For each year of the period, we compute a ratio as the sum of non-missing 4d values in all countries in the selected year divided by the sum of their parent 3d values. Therefore, r_6 is a set of year-ratios $\{r_{6,t}^o\ , t \in T^o\}$, as a time-dimensional version of r_1. As such, it is more sensitive to countries with high employment levels, since it considers aggregated absolute values in both numerator and denominator.

[6] $$r_{6,t\in T^o}^o = \frac{\sum_c E_{c,t}^{o_{4d}}}{\sum_c E_{c,t}^{o_{3d}}} \qquad \text{for } c \in C_{4d,t}^o,\ t \in T^o,\ o \in O_{ICT}$$

Estimates

Once the six ratios are computed, we can provide six different estimates by multiplying the ratio by the parent 3d value in countries with missing 4d data:

[7] $$\widehat{E_{c,t}^{o_{4d},j}} = r_{j,t}^{i} \cdot E_{c,t}^{o_{3d}} \qquad \text{for } c \in C_m^o,\quad t \in T^o,\ o \in O_{ICT},\ j \in \{1,2,3,4,5,6\}$$

where $r_{j,t}^{i} = r_j^i$ for $j \in \{1,\dots,4\}$, i.e., for numeric ratios r_1 to r_4, the ratio is the same for all years in the period, while for vector ratios r_5 and r_6, there is a different ratio per year in the period.

Step 2.2. Countries where 4d data is available for some years

This is the case of, for instance, Belgium and Germany (missing only 2011 for the ISCO-08 period), Cyprus (missing 2011 to 2014), Italy (missing 2011-2016); there are no similar cases in the time period 2004-2010. In this case, instead of using data from all the 22 countries providing 4d data at least one year, we decide to use the own country´s data as the best predictor[11]. Hence, in this case, each country is treated independently and uses only data from their own country for the available years. We compute the in-country-ratio for occupation *o* and country *c*, $r_{I,c}^{o}$as:

[8] $$r_{I,c}^{o} = \frac{\sum_t E_{c,t}^{o_{4d}}}{\sum_t E_{c,t}^{o}} \qquad \text{for } t \in T_c^o,\ o \in O_{ICT}$$

Then,$r_{I,c}^{o}$ is used to estimate the 4d values in years in which 4d data is missing for country *c*:

[9] $$\widehat{E_{c,t}^{i_{4d}}} = r_{I,c}^{o} \cdot E_{c,t}^{o_{3d}} \qquad \text{for } t \in T^o \setminus T_c^o,\ o \in O_{ICT}$$

Overview of 4d data in reporting countries

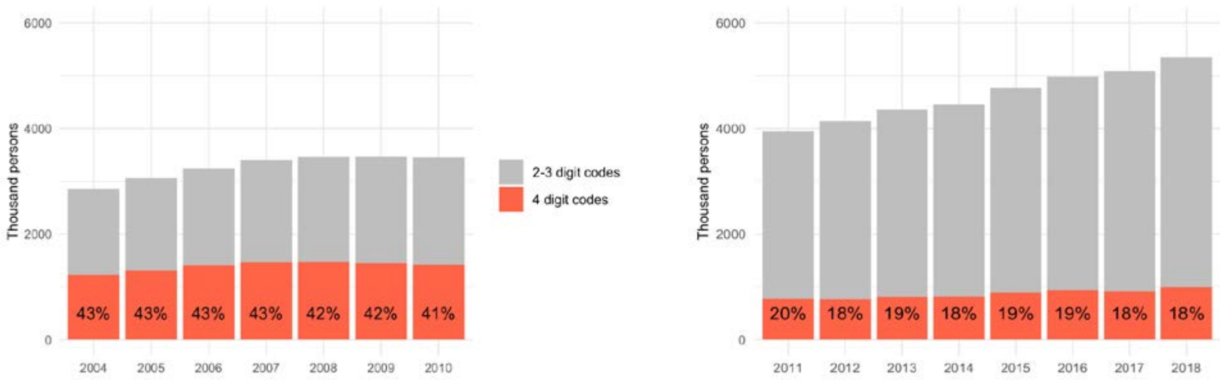
This subsection presents an overview of the employment in 4d occupations in reporting countries. The 4d values and their corresponding 4d over 3d ratios presented here are the ones used to compute the six ratios r_1 to r_6 defined above, which are then applied to estimate missing 4d values. This overview of 4d data may be useful for the selection of the final ratio to be used. We present the weight of 4d occupations in overall ICT specialists' employment (Figure 1), the individual weight of each 4d occupation (Figure 2), the weight of countries´ employment in the 4d occupations (Figure 3), and the ratios (4d over 3d) per occupation, country and year (Figure 4).

[11] The rationale for this decision is the observation that intra-country variation of ratios over time (measured by the standard deviation of ratios) is lower than inter-country variation in the same year, or across time. This may be caused by a number of factors, among which the fact that the data source (LFS) is a panel survey, with a partial overlap in the sample across waves. Other possible reason is rooted in the intrinsic meaning of the ratio, namely the proportion of workers in certain 4d occupation in the wider 3d parent group, which is not expected to have big variations in short periods of time in a country, but rather depend on longer cycles of labour market supply and demand and technological development and uptake in the country.

Figure 1 presents the weight of 4d occupations in overall ICT specialists' employment. It shows that 4d occupations account for more than 40% of all ICT specialists' employment in the period 2004-2010, and around 18-20% in 2011-2018, which is an important share of employment that needs to be estimated for non-reporting countries.

Figure 1. Weight of 4d occupations in overall ICT specialists' employment in: a) 2004-2010, b) 2011-2018

(a) 2004-2010 (b) 2011-2018



Notes: Data from countries reporting 4d occupations all years in each period. The percentages in orange bars are the share of 4d occupations´ employment (orange bars) computed over all ICT specialists' employment in each year, i.e., over the sum of 2 and 3 digit occupations´ employment (grey bars) and 4d occupations´ employment.

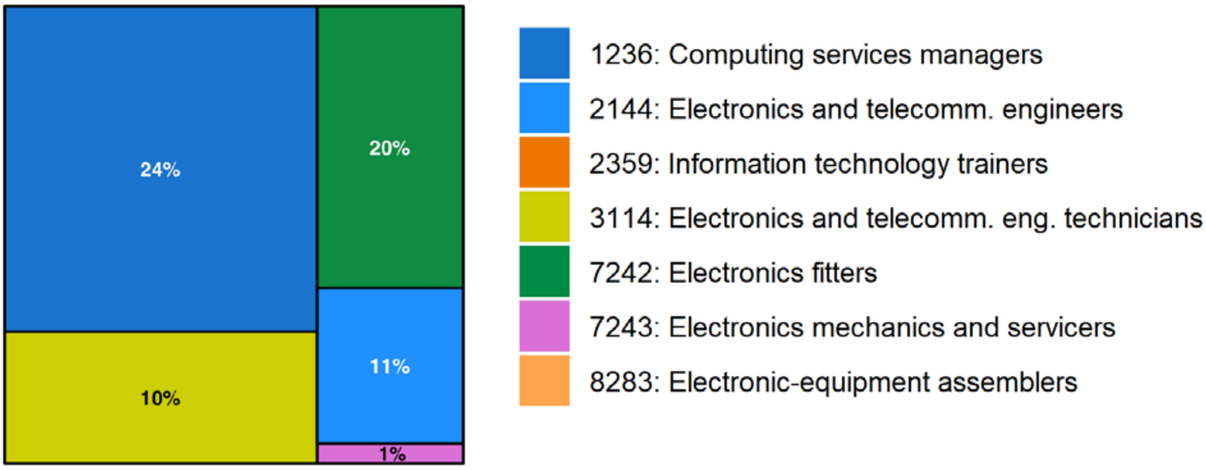
Source: JRC elaboration based on Eurostat.

Figure 2 shows the distribution of employment in 4d occupations per occupation. It can be seen that not all 4d occupations contribute equally to employment. For instance, in the period 2011-2018 (Figure 2b), occupations *2152* (Electronic engineers) and *2116* (Graphic and multimedia designers) together represent more than half of the labour force in all the 4d occupations considered, and near 10% of all ICT specialists' employment.

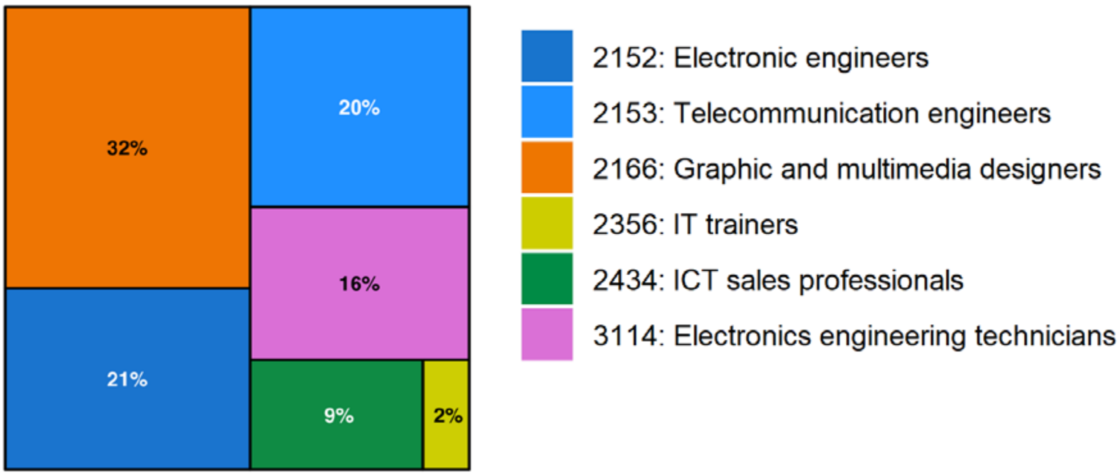
On the other hand, occupations *2434* (ICT sales professionals) and *2356* (Information technology trainers) only account for 11% of employment in 4d occupations, and 2% of total ICT specialists' employment. In view of the above, we may prefer the estimators minimising error in occupations with higher weight.

Figure 2. Average distribution of 4d occupations in periods: a) 2004-2010, b) 2011-2018 (%)

(a) 2004-2010



(b) 2011-2018



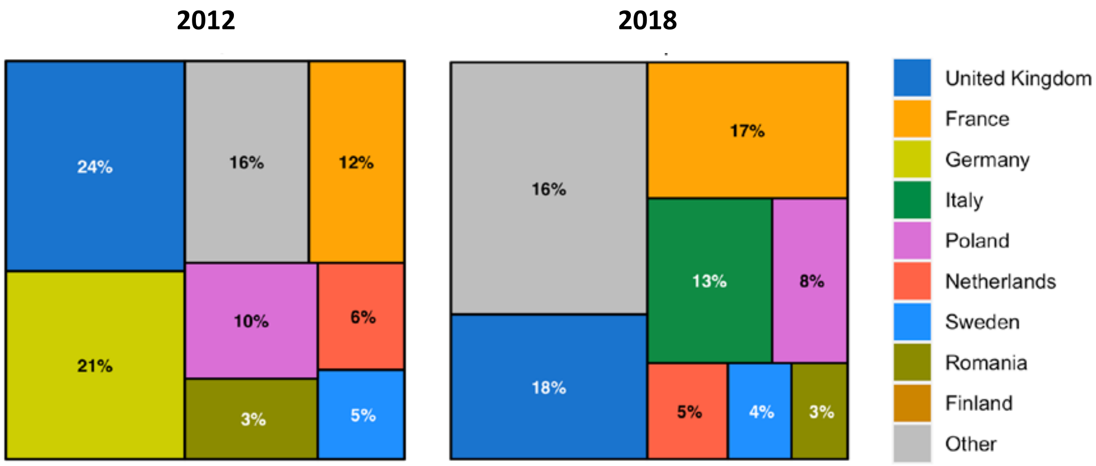
Notes: Data from countries reporting 4d occupations all years in each period. The percentages are computed over the sum of 4d occupations´ employment.

Source: JRC elaboration based on Eurostat.

Another important aspect to consider is the relative weight of countries in employment in 4d occupations. Since some ratios are computed with aggregated absolute values for all countries in a certain year, as r_4 or r_6 (both summarising across countries per year), or even in all years, as r_1 (overall ratio, summarising across countries and years), these are mostly driven by the value of employment in countries with higher shares.

As shown in Figure 3, three reporting countries -United Kingdom, Germany and France- add up more than half of all ICT specialists in these 4d occupations, hence being the most important contributors to ratios relying on aggregated absolute values, like ratios r_1, r_4 and r_6.

Figure 3. Employment in 4d occupations by country, 2012 and 2018 year (%)



Notes: Data from countries reporting any 4d code in the referred years. The percentages are computed over the sum of 4d occupations´ employment in countries that report data.

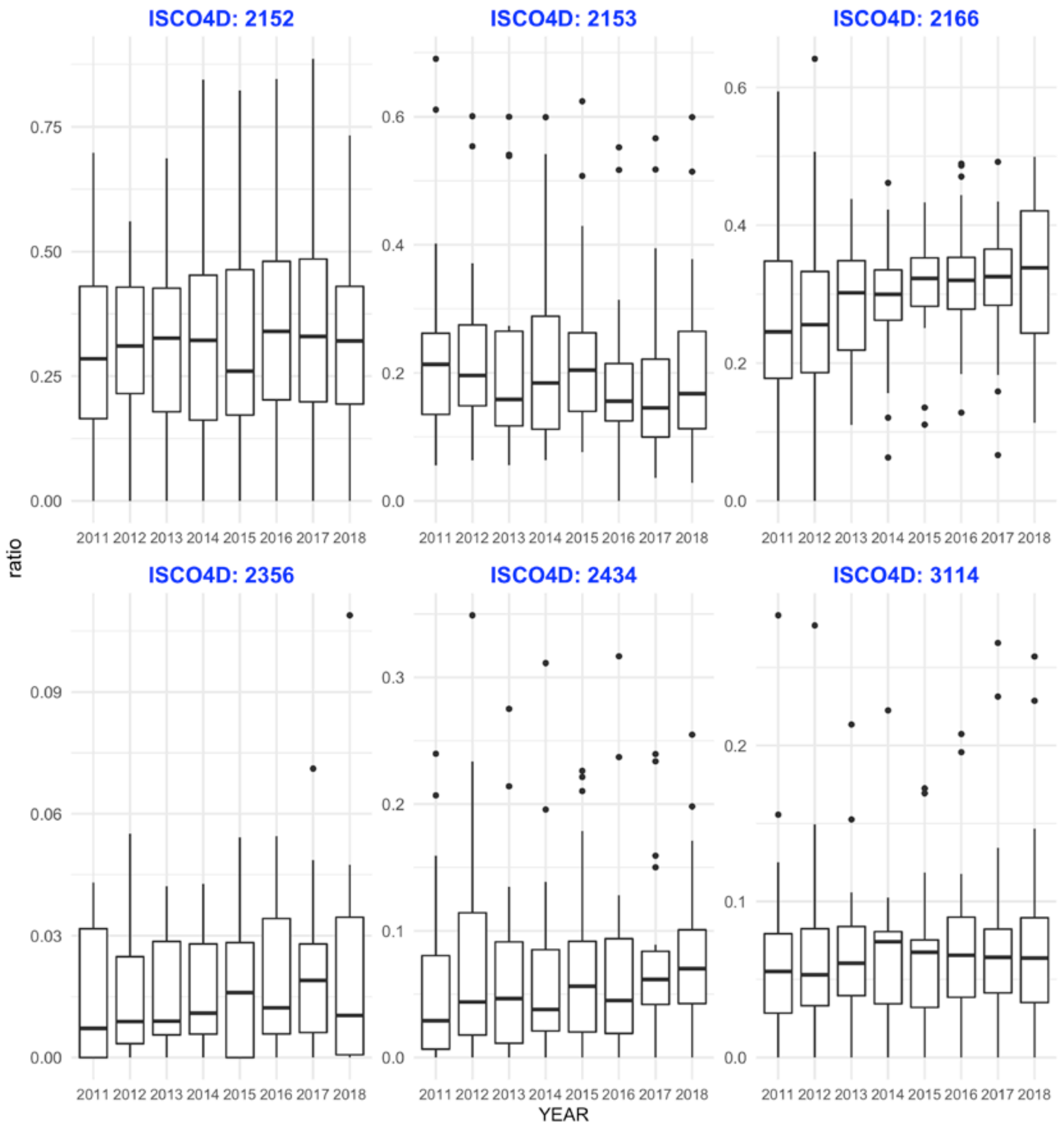
Source: JRC elaboration based on Eurostat.

Additional information relevant to the choice of the ratio is presented in Figure 4, that shows in a compact way the distribution of the ratios of 4d over parent 3d values for all 22 countries reporting 4d data at least once in the period 2011-2018. The exploration of the ratio provides an overview in relative terms, not affected by country size, and hence comparable across countries.

First, we can observe the inter-occupation variability of ratio values, with medians varying from values close to 0 for occupation *2356* (Information technology trainers) to values around 0.3 for occupations *2152* (Electronic engineers) or *2166* (Graphic and multimedia designers).

Second, we can see that some countries' ratios are outliers for specific occupations and years. In general, the outliers appear in the upper bound of the distributions, hence expected to have an inflating effect on the estimates. In particular, the generalisation of upper outliers shown in the ratios of most occupations (only occupation *2166* presents outliers in the lower bound of the distribution) would also inflate ratio estimators based on country-year ratios, such as r_2 or r_5. A countermeasure to this would be to filter out outliers before computing the estimates.

Figure 4. Country distribution of 4d/3d ratios per 4d code and year, 2011-2018



Notes: Data from countries reporting 4d occupations at least one year.

Source: JRC elaboration based on Eurostat.

Comparison of methods' predictability

Measure of performance

To determine which is the best estimator given the available data, in this section we compute the estimations using the Education filter method and the Ratio method's six variants, and then we compare them using a performance measure. The elements presented in the previous subsection are considered for the final choice of the best estimate.

To compare the methods, we first compute employment estimations for 4d occupations according to the two methods at hand: the EF method and the Ratio method, then we analyse which method better approximates the values in the countries reporting 4d data. To that end, we implement the EF method as previously described, and six estimations based on the ratio estimators defined above. Therefore, we will produce one EF and six Ratio estimates on the number of ICT specialists per country, occupation and year, limited only to the 4d occupations and the 22 reporting countries. To assess the accuracy of the methods, we apply each imputation method to the countries reporting 4d values and compare the estimations with the actual values. Two different error measures are used: Root Square Mean Error (RSME), which gives higher weights to large errors, hence more useful when large errors are particularly undesirable; and Mean Absolute Error (MAE), which weights all errors equally and is more robust to outliers in absolute values. They are negatively-oriented scores, in the sense that lower values are better. The choice of the most appropriate performance measure is widely discussed in literature (Chai and Draxler, 2014), and it depends on a number of objective factors such as the assumptions we can make on the unbiasedness of estimators or the functional distribution of the errors; and subjective ones such as how willing we are to tolerate large errors in our estimates. Nevertheless, a single metric is not enough to assess the performance of a model, and therefore we proceed computing both RMSE and MAE. The formulas for RSME and MAE are:

[9] $$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(\hat{x_i} - x_i)^2}{n}}$$

[10] $$MAE = \sum_{i=1}^{n} \frac{|\hat{x_i} - x_i|}{n}$$

$$for\ observation\ x_i\ \ and\ predicted\ value\ \widehat{x_i}$$

For occupations corresponding to the same 3d parent group, such as *7242* and *7243* under ISCO-88, the EF method does not provide separate estimates for each occupation, but a single value for the group {*7242*, *7243*}[12]. This is also the case for occupations {*2152*, *2153*} under ISCO-08. In those cases, to allow for comparison between the two methods, we apply the Ratio method for each occupation and then aggregate the estimations before computing the error measures.

The error measures may be computed at different levels of aggregation:

1. An overall error measure averaged among all years, occupations and countries, which provides a summary error measure per period, 2004-2010 or 2011-2018.
2. Error measures by occupation, to analyse how methods behave in each occupation individually.

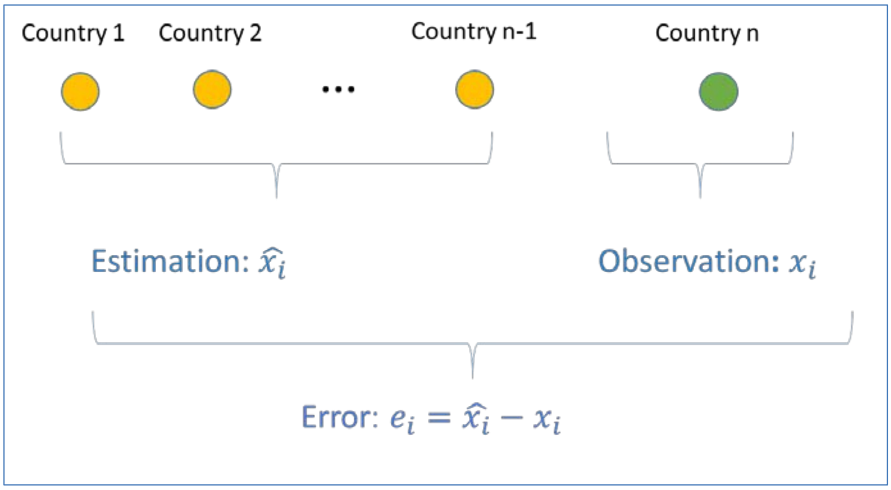
[12] This is because the EF method applies the education filter to data from the parent 3d occupation, which is the same for all the 4d occupations sharing the parent group.

3. Error measures by year, to analyse a possible effect of time on the accuracy of the method.

Due to the fact that the Ratio method makes use of data from all the countries reporting 4d employment, we apply a cross-validation method in order to test the method in those same countries. Cross-validation methods are used to estimate prediction error and evaluate statistical models. K-Fold Cross-Validation in particular is generally used to assess performance of the prediction model in small samples. It consists in estimating and testing the method in K subsamples of the data, in order to increase evaluation robustness (Hastie et al., 2009). In this work, we apply a variation of the Leave-One-Out Cross-Validation[13] (LOOCV), in a way that the estimation for each country is performed using only other countries´ data (Figure 5). For example, to estimate data for Austria (AT) with ratio r_1, we apply the method computing the LOOCV-ratio, $loocv\ r_{1,AT}^{o}$, with all countries but Austria:

[8] $$loocv\ r_{1,AT}^{o} = \frac{\sum_{c,t} E_{c,t}^{o_{4d}}}{\sum_{c,t} E_{c,t}^{o_{3d}}} \qquad \text{for } c \in C_{4d,t}^{o} \setminus \{AT\},\ \ t \in T^{o},\ \ o \in O_{ICT}$$

Figure 5. Leave-One-Out Cross-Validation



Source: JRC elaboration.

The estimates of employment in countries reporting 4d data computed using the LOOCV-ratios, $\widehat{loocv\ E}_{c,t}^{o_{4d}}$, are then used to compute the error measures for the Ratio method. This way, under the assumption that employment in ICT occupations behaves similarly in the countries providing data and those not providing them, we may conclude that this method would work with similar accuracy on countries with missing data.

Performance analysis

The results show that for most occupations and years, the Ratio method is more accurate than the EF method with both RMSE and MAE. Also the overall error measure is lower for the Ratio method.

[13] When K equals the number of observations (N), N-1 observations are used to predict the remaining observation.

Overall RMSE and MAE

Table 5 shows the resulting error measurements for the EF and the six Ratio estimates for the two performance measures, RMSE and MAE, two periods, 2004-2010 and 2011-2018, and considering the option of removal of ratio outliers as suggested in the previous subsection (Figure 4). The main conclusion is that in all cases the Ratio method outperforms the EF method. The overall error reduction ranges from 35% to 55%, depending on the choice of performance measure, period and removal of outliers. It has to be noted that by definition direct comparison between RMSE and MAE is not possible, they are useful to compare between methods under the same parameters (period and outlier removal). The second conclusion is that the removal of outliers prior to the computation of the final ratios has a slight positive effect in the error (yielding lower errors), more noticeable in ratios r_2 and r_5, as expected, but also in r_3. According to Table 5, the best ratio is r_1 or r_3 in the period 2004-2010, and r_2 or r_3 for 2011-2018.

For the rest of the section, we will show only the performance comparison for the option that includes removal of outliers.

Table 5. Overall error measurements for EF and Ratio methods

Period	***EF***	***Ratio r1***	***Ratio r2***	***Ratio r3***	***Ratio r4***	***Ratio r5***	***Ratio r6***	***Best method***	***% error reduction: Best method vs EF***
RMSE									
With outliers removal									
2004-2010	*35.2*	***22.7***	*24.3*	*24.3*	*22.7*	*24.3*	*22.8*	*Ratio r1*	*35%*
2011-2018	*23.2*	*12.0*	***10.5***	*10.5*	*11.9*	*10.6*	*12.2*	*Ratio r2*	*55%*
Without outliers removal									
2004-2010	*35.2*	***22.7***	*23.1*	*23.2*	*22.8*	*23.2*	*22.8*	*Ratio r1*	*35%*
2011-2018	*23.2*	*12.0*	***11.6***	*11.9*	*12.0*	*11.6*	*12.2*	*Ratio r2*	*50%*
MAE									
With outliers removal									
2004-2010	*13*	*8.2*	*7.8*	***7.5***	*8.1*	*7.8*	*8.2*	*Ratio r3*	*43%*
2011-2018	*9.8*	*4.7*	*4.5*	***4.5***	*4.6*	*4.5*	*4.8*	*Ratio r3*	*55%*
Without outliers removal									
2004-2010	*13*	*8.2*	*7.9*	***7.9***	*8.2*	*8*	*8.2*	*Ratio r3*	*39%*
2011-2018	*9.8*	*4.7*	*4.6*	***4.7***	*4.6*	*4.6*	*4.8*	*Ratio r3*	*53%*

Notes: 'Outliers removal' consists in the removal of country-year ratios that are outliers prior to the computation of the final ratio. Bold font highlights the error of the best method in each row.

Source: JRC estimation.

RMSE and MAE by occupation

The main conclusion of the analysis of RMSE and MAE by occupation is a clear preference for the Ratio method, although without a single preferred ratio for all the occupations (Table A. 1 and Table A. 2 in the Annex). However, there is almost perfect concordance of preferred methods yielded by both error measures considered (RMSE and MAE). Even if we concentrate on the occupations with higher relative weights in the final estimate of ICT specialists' in 4d occupations, i.e., *1236*, *2359* and *7242-7243* in 2004-2010 and *2152-2153*, *2166* and *3114* in 2011-2018 (Figure 2), the preferred ratios vary between r_1 and r_3 for 2004-2010 and r_2, r_3, r_4 and r_5 for 2011-2018. Another conclusion is that the Ratio method does not improve the EF method by the same percentage for all occupations. For instance, in occupation *1236* (ISCO-88), the RMSE of the best ratio (r_1) is only 23% lower than the corresponding to EF; but the reduction of error reaches 87% in occupation *2359*, when comparing r_3 and the EF method. Similar examples are found among the occupations covered by ISCO-08 in the period 2011-2018.

RMSE and MAE by year

The results are more homogeneous when computing the overall error measure per year, considering all the occupations together (Table A. 3 and Table A. 4 in the Annex). In this case there is a strong preference for ratios r_6 or r_3 for years 2004 to 2010 (occupations under ISCO-88) and for ratios r_3 or r_5 for the period 2011-2018 (ISCO-08). The Ratio method generally provides error measures lower than the ones by the EF method: in 2004-2010 the improvement lies between 34% and 44%, depending on the error measure and year considered; for the period 2011-2018 the Ratio method reduces de error of the EF method by around 55%. Both methods are more accurate (lower errors) in the second period. We attribute this to the higher proportion of employment to be estimated in the first period: more than 40% of all ICT specialists' employment is due to 4d occupations under ISCO-88 (Figure 1), and because only 16 countries provided data at 4d level until 2010, with big countries such as Germany, France, Italy or Spain among those not providing 4d data. Further research would be needed in order to establish causality and to unveil the underlying factors.

Summarising, the Ratio method consistently shows lower error measures with the two performance measures used –RMSE and MAE-. The preferred ratio is not the same for all years, occupations, or even time periods. Because there is a break in the series in 2011, we may consider using a different ratio for each period. Being our goal to minimise the aggregate error –all occupations together- at EU level every year, we would choose among the best performing methods per year, as shown in Table A. 3 and Table A. 4 in the Annex. Therefore, we propose to apply the Ratio r_3 method for the estimation of ICT specialists in 2004-2010 and Ratio r_5 for 2011-2018. In this second period, the performance comparison per year provides several candidates: r_2, r_3 and r_5; our selection of r_5 follows the intuition that a ratio that considers yearly data might provide better estimates in the coming years, instead of using a ratio that considers all years in block. However, as seen in this subsection, the differences of performance between the ratios are not so prominent, and a different choice might be justified.

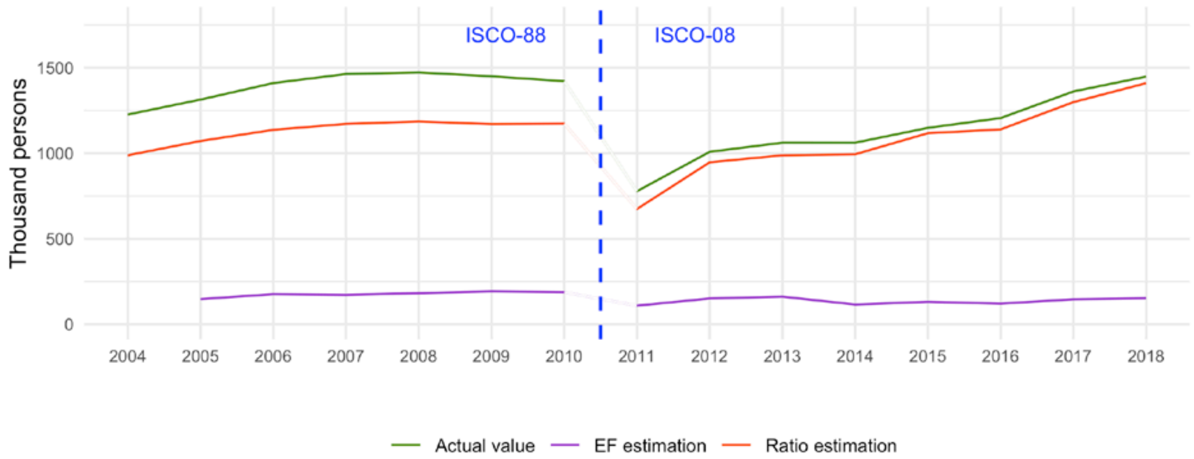
The following sections provide the ICT specialists' employment estimates computed using these selected methods: r_3 for 2004-2010 and r_5 for 2011-2018.

Comparison of estimations vs actual value in reporting countries

This subsection presents a graphical way of assessing the methods. Figure 6 shows the two estimations –EF and Ratio- for the aggregate of the 22 countries providing 4d data at least one year in the period 2004-2018. The actual values reported by these countries are also shown in the plot. As suggested by the results of the performance analysis, we are using ratio r_3 for the period 2004-2010 and r_5 for 2011-2018. The underestimation of the EF method stated above is clearly seen here. On the other hand, the Ratio method seems to estimate employment more accurately, but still showing a relatively high underestimation in the period 2004-2010, although much lower in 2011-2018.

The series break introduced by the revision of the ISCO classification in 2011 is clearly observed in Figure 6. As anticipated in the description of the methods, the lack of a one-to-one correspondence of 4d occupations between ISCO-88 and ISCO-08 had an impact on the operational definition of ICT specialists in employment. The occupations considered to be ICT specialists under ISCO-08 seems to be more restrictive than the ones under ISCO-88, thus causing the sharp decrease in the estimate between 2010 and 2011.

Figure 6. Actual value vs EF and Ratio estimation of 4d occupations in reporting countries. All occupations aggregated, 2004-2018



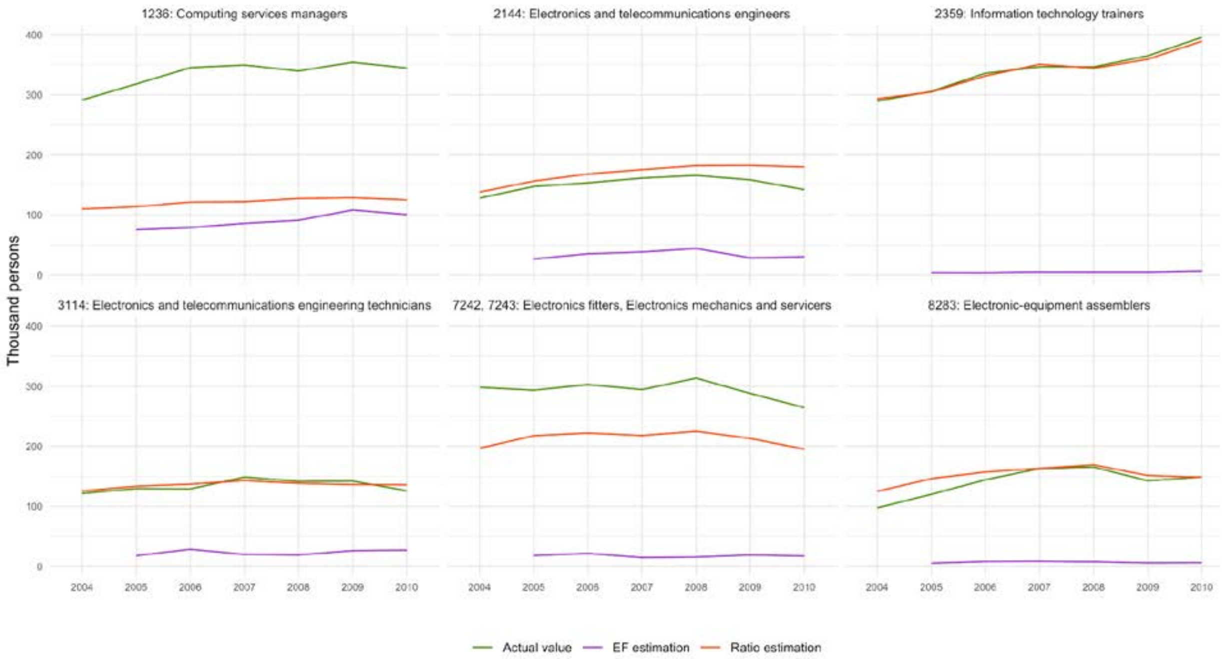
Notes: Ratio r3 used for 2004-2010, ratio r5 used for 2011-2018. Data from countries reporting 4d data at least one year

Source: JRC estimation and Eurostat.

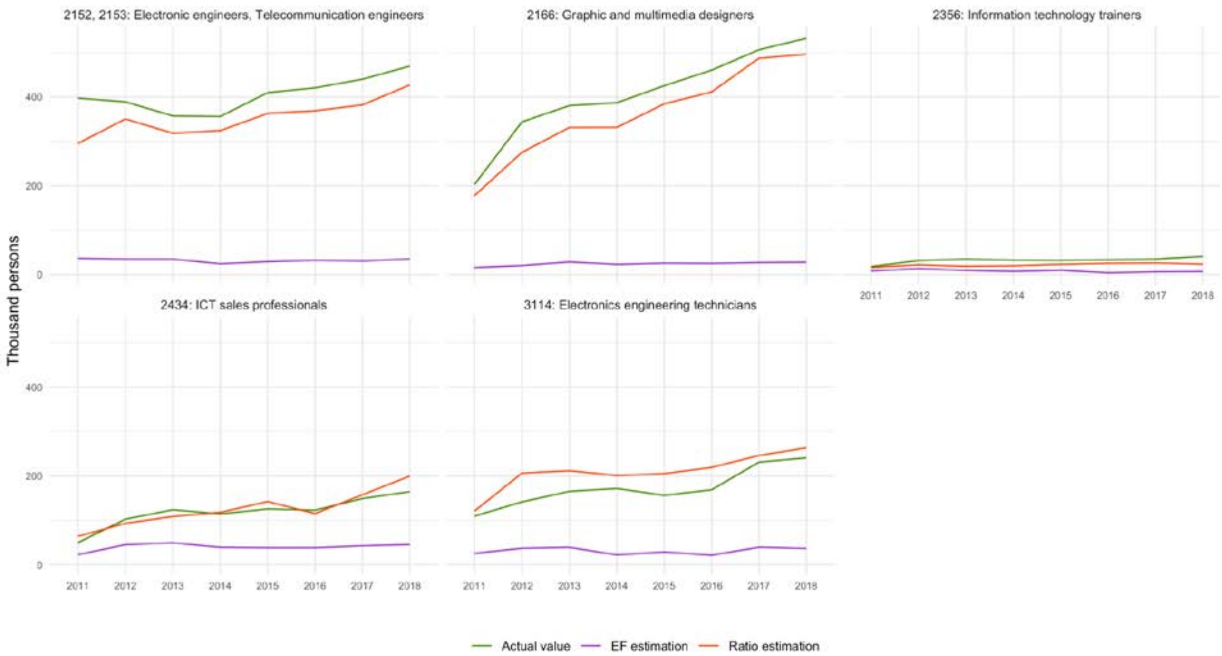
When looking at individual occupations in the period 2011-2018 (Figure 7b), in some cases the Ratio method clearly outperforms the EF method, e.g. in occupations *2152-2153* or *2166*, but in other cases the distance is considerably reduced, e.g. occupation *2356*. It can also be seen that the EF method always underestimates the actual value, while the Ratio method sometimes underestimates (occupations *2152-2153*, *2166* and *2356*) and sometimes overestimates (occupation *3114* and some years in occupation *2434*). We can see similar results in the period 2004-2010 with ISCO-88 occupations (Figure 7a). A more detailed analysis of potential determinants that explain these discrepancies fall out of the scope of this study.

Figure 7. Actual value vs EF and Ratio estimation of 4d occupations in reporting countries by occupations, 2011-2018

(a) 2004-2010



(b) 2011-2018



Source: JRC estimation and Eurostat.

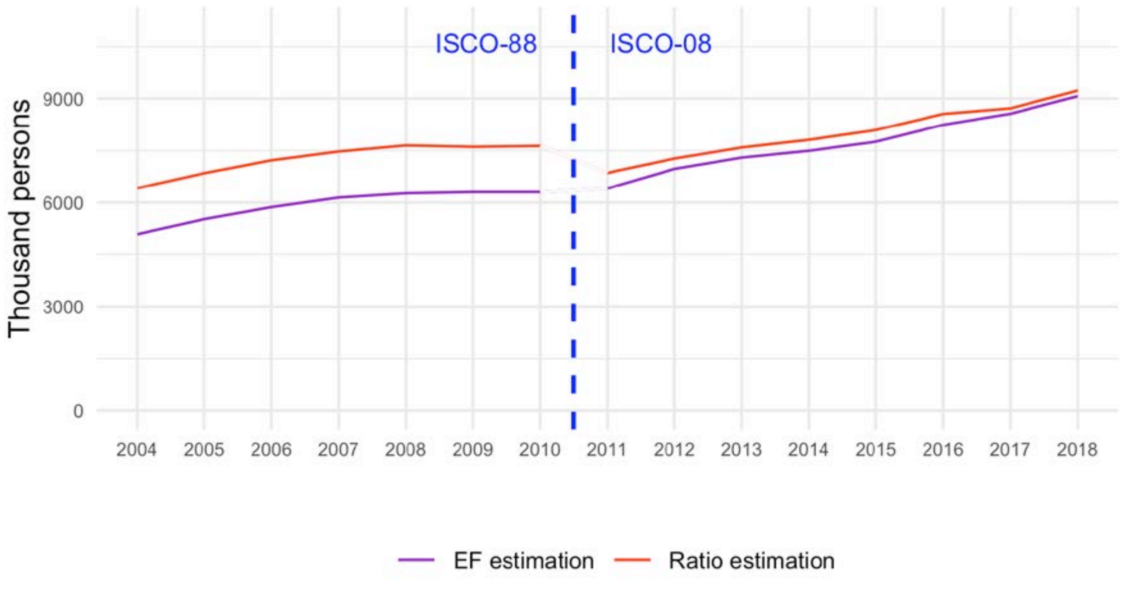
Estimation of ICT specialists in 2004-2018

Results with the Ratio and the EF methods

Figure 8 shows the estimates of ICT specialists in the European Union from 2004 to 2018, after imputing the countries with missing values at 4d level with both the Ratio and EF methods (data in Table A. 5 in the Annex). The difference between the two estimates is above 1.3 million persons every year in the period 2004-2010, with the Ratio method estimating between 21% and 26% more employment than the EF method. Since 2011, the gap between the two estimates gets reduced to 7% (or 450 thousand persons) in 2011 and 2% (or 160 thousand persons) in 2018. This is explained by a lower proportion of employment to be estimated: on the one hand, the share that 4d occupations have over total ICT specialists' employment is higher in the first period (around 40%) than in the second one (around 18-20%) (Figure 1); on the other hand, the number of countries reporting 4d occupations increases over time, with already 22 EU Member states reporting 4d data in 2018, and 16 in 2006. Therefore, the vast majority of employment in the last period is reported by Member States, with very little margin of difference between the two estimation methods.

As observed in Figure 8, the break in the series is lighter for the EF method in comparison with the Ratio method. However, this is only an apparent difference, caused by the strong underestimation that characterises the EF method, as explained above (Table 4 and Table A. 7 and Table A. 8 in the Annex). As the EF method yields very low values for employment in 4d occupations, the effect of the lack of comparability in 4d occupations due to the revision of the ISCO is much stronger felt by the Ratio method´s estimation.

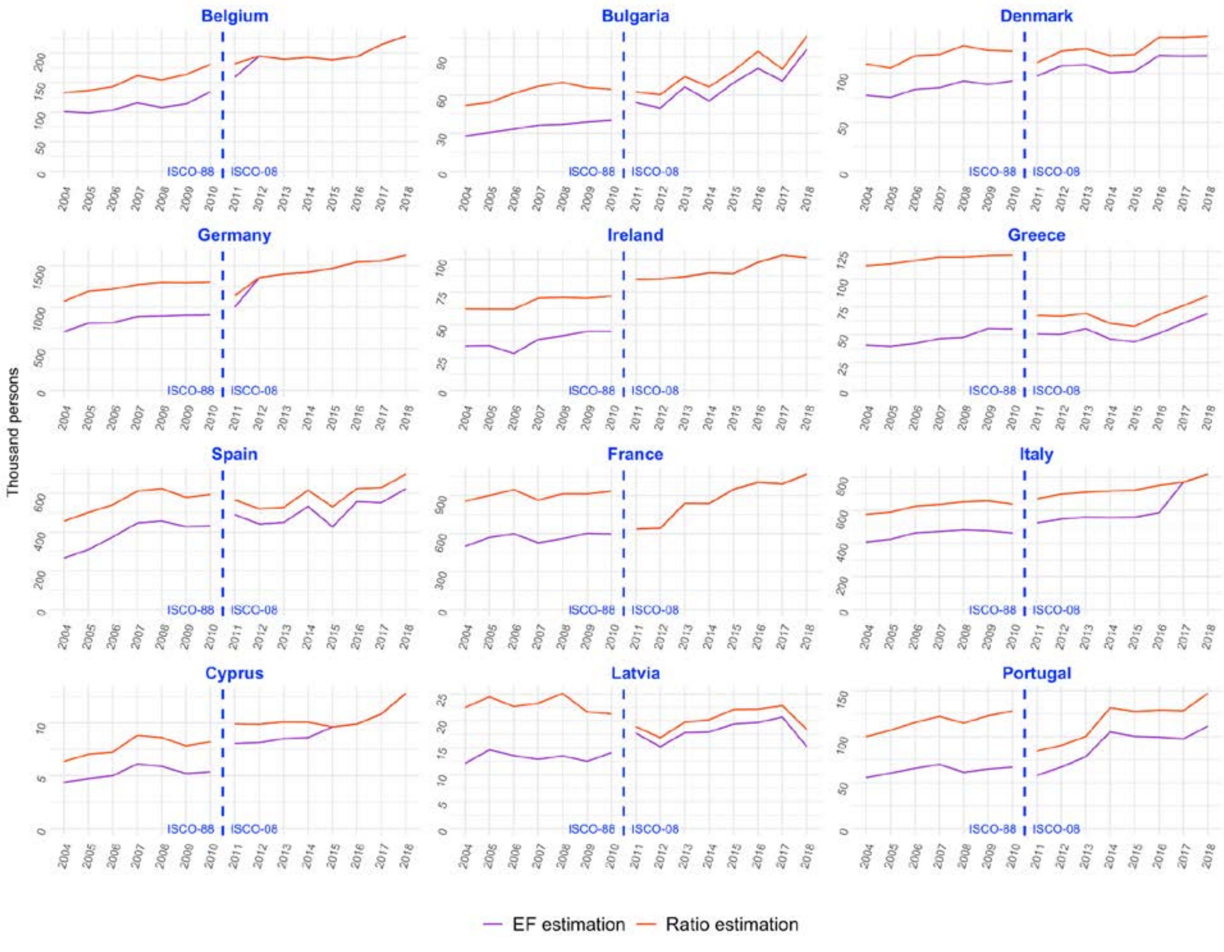
Figure 8. Estimates of ICT specialists' employment in the EU by method, 2004-2018



Source: JRC estimation.

Table 6 shows the estimate of ICT specialists' employment by Member State, where missing 4d occupations are estimated using the Ratio method (cells in blue font indicate the countries and years in which the imputation of 4d occupations has been performed). Figure 9 shows, for the 12 countries that needed imputation at least one year in 2004-2018, the estimates using the Ratio and the EF methods. The Ratio estimates are higher than the EF in all cases, with differences ranging from 6% in Latvia (2011), to 65% in Greece (2005), and on average being much lower in the period 2011-2018 (17%) than in 2004-2010 (34%) (Table A. 6 in the Annex). In absolute terms, countries with high employment levels show the biggest differences: Germany, France, Italy and Spain (Table 7). The difference in the results of the two estimation methods is especially high in 2004-2010, accounting for more than one million persons every year of that period for the aggregate of the four countries. In 2018, the difference between the Ratio and EF estimates in the six countries not reporting 4d data accounts for 160 thousand persons.

Figure 9. Estimation of ICT specialists in the 12 Member States with missing data, 2004-2018



Note: Data from countries reporting 4d data for part of the period (i.e. Belgium, Germany, Ireland, France, Italy and Cyprus) show identical values for the EF and Ratio lines for the reporting years, corresponding to their actual non estimated values.

Source: JRC estimation.

Table 6. ICT specialists' employment in the EU by Member State (Ratio method), 2004-2018 (thousand persons)

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Belgium	*132.9*	*136.5*	*143.0*	*161.8*	*154.4*	*163.7*	*180.5*	*181.9*	194.9	189.3	192.4	188.4	193.8	214.3	228.6
Bulgaria	*51.7*	*54.1*	*61.3*	*66.9*	*69.9*	*65.9*	*64.5*	*62.5*	*60.3*	*74.6*	*66.4*	*79.0*	*94.3*	*80.4*	*106.4*
Czechia	135.5	154.1	166.3	184.5	202.6	201.7	203.5	158.6	168.6	183.6	168.1	184.6	180.9	184.9	218.3
Denmark	*109.6*	*105.4*	*117.9*	*119.2*	*128.3*	*123.4*	*122.8*	*110.9*	*122.7*	*125.1*	*118.1*	*119.2*	*136.8*	*136.8*	*138.1*
Germany	*1069.4*	*1190.3*	*1217.0*	*1269.3*	*1295.9*	*1292.1*	*1299.4*	*1139.3*	1353.5	1397.2	1417.9	1465.6	1541.1	1555.9	1622.7
Estonia	17.4	13.6	17.5	20.9	22.7	21.4	22.3	20.8	23.3	25.7	24.5	28.5	34.1	36.9	37.9
Ireland	*62.2*	*62.0*	*62.0*	*70.4*	*70.9*	*70.3*	*71.8*	84.5	85.0	86.7	89.6	89.1	97.6	103.1	101.2
Greece	*112.0*	*113.7*	*116.7*	*119.8*	*119.8*	*121.1*	*121.5*	*67.4*	*66.7*	*69.2*	*60.2*	*57.6*	*68.0*	*76.2*	*85.1*
Spain	*456.3*	*501.2*	*540.8*	*611.2*	*624.4*	*579.1*	*593.6*	*565.6*	*520.4*	*527.1*	*615.7*	*530.5*	*624.7*	*628.9*	*698.2*
France	*856.4*	*900.9*	*946.4*	*864.2*	*914.9*	*914.0*	*934.1*	636.6	642.0	838.6	836.8	950.1	1003.8	992.3	1068.3
Croatia	23.3	26.7	28.8	33.3	38.9	38.3	35.5	38.8	38.9	38.7	42.0	42.7	52.3	53.5	57.7
Italy	*575.0*	*588.2*	*624.3*	*634.9*	*651.7*	*656.7*	*637.4*	*669.4*	*697.9*	*709.6*	*716.7*	*721.2*	*750.2*	769.9	817.5
Cyprus	*6.4*	*7.0*	*7.2*	*8.8*	*8.6*	*7.8*	*8.2*	*9.9*	*9.9*	*10.1*	*10.1*	9.6	9.9	10.8	12.8
Latvia	*22.5*	*24.5*	*22.7*	*23.3*	*25.1*	*21.7*	*21.3*	*18.9*	*16.9*	*19.7*	*20.2*	*22.1*	*22.1*	*22.8*	*18.4*
Lithuania	24.7	21.6	20.1	24.8	27.3	24.1	22.7	22.9	24.3	23.4	23.0	27.9	34.1	36.9	37.5
Luxembourg	7.0	7.7	6.2	7.1	9.2	9.9	10.2	9.8	11.9	11.6	12.7	12.0	10.8	13.6	15.6
Hungary	162.9	155.5	161.7	161.4	163.1	151.7	155.4	102.0	123.5	136.8	144.2	152.6	158.1	157.7	165.6
Malta	2.7	3.0	6.0	9.1	8.7	7.5	7.6	5.4	5.9	6.1	6.8	7.5	8.1	9.4	11.5
Netherlands	327.7	310.5	292.0	309.9	324.7	318.5	332.7	366.7	381.1	382.7	403.5	412.7	422.2	432.2	475.5
Austria	100.0	109.8	119.1	121.9	126.9	132.5	134.1	145.0	147.0	152.6	149.3	166.6	178.6	187.8	191.8
Poland	302.7	332.7	376.5	416.4	437.8	464.7	437.8	354.5	393.2	403.4	413.1	423.7	431.8	452.0	486.3
Portugal	*100.0*	*107.1*	*115.4*	*122.2*	*114.8*	*122.9*	*128.0*	*84.5*	*90.6*	*100.2*	*131.4*	*127.5*	*128.9*	*128.3*	*147.1*
Romania	0.0	104.2	158.6	171.4	173.5	166.7	139.6	124.8	139.1	136.4	139.9	160.8	167.7	185.4	190.1
Slovenia	28.6	32.8	34.0	32.1	35.3	35.4	34.8	33.1	30.7	30.4	32.1	32.9	32.1	36.1	38.9
Slovakia	53.9	64.2	76.4	81.4	81.2	79.4	81.6	62.3	58.4	59.4	65.3	68.1	73.2	70.5	81.7
Finland	118.3	124.8	130.7	131.7	140.1	128.2	135.3	137.9	145.7	158.9	156.5	157.7	162.3	168.2	181.7
Sweden	220.9	243.8	245.0	254.0	265.7	266.7	267.3	258.1	270.0	267.3	276.9	293.8	310.8	332.9	345.8
United Kingdom	1331.1	1350.3	1404.7	1440.9	1411.7	1423.2	1429.8	1382.1	1447.3	1424.2	1476.0	1559.4	1626.2	1637.1	1648.6

Note: Cells in Italic blue font include imputed 4d occupations' employment.

Source: JRC estimation and LFS.

Table 7. Differences between Ratio and EF methods' estimates of ICT specialists by Member State, 2004-2018 (thousand persons)

	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Belgium	31.8	38.1	39.3	46.1	46.5	49.8	46.1	22.7							
Bulgaria	23.9	23.6	28.1	30.7	33.0	27.1	24.4	8.5	10.5	8.1	11.1	9.4	13.4	9.4	10.5
Denmark	32.0	30.0	34.3	33.9	36.1	34.7	30.5	13.6	15.2	16.3	17.5	17.2	18.5	19.1	20.0
Germany	364.9	383.3	404.1	384.9	404.1	391.6	393.9	139.0							
Ireland	28.4	27.9	33.9	31.5	29.4	25.3	26.8								
Greece	71.3	74.1	74.5	73.3	72.1	65.4	66.2	16.7	16.3	13.7	14.0	13.9	16.8	15.7	16.1
Spain	191.0	191.8	166.3	164.7	167.5	150.9	161.5	75.9	79.2	77.4	83.3	103.4	67.3	77.4	75.0
France	357.5	331.6	348.3	336.9	355.5	312.1	336.6								
Italy	167.0	164.6	161.2	163.0	170.2	180.1	174.8	145.6	150.4	150.9	160.7	162.9	165.4		
Cyprus	2.0	2.3	2.2	2.7	2.7	2.6	2.8	1.8	1.8	1.6	1.5				
Latvia	10.4	9.9	9.1	10.4	11.6	9.2	7.2	1.2	1.7	1.9	2.3	2.7	2.4	2.1	3.2
Portugal	44.6	46.6	49.9	52.3	53.6	58.2	61.1	26.5	23.6	21.8	26.1	27.2	29.4	30.6	35.7

Note: Empty cells are not subject to imputation, since 4d data are reported for those years.

Source: JRC estimation.

Trends of ICT specialists' employment in Europe

The number of ICT specialists in employment follows an increasing trend during the two analysed periods (2004-2010 and 2011-2018)[14]. In the second period, the employment of ICT specialists increased by 35% from 6.9 million persons in 2011 to 9.2 million in 2018 (Table 8). The number of ICT specialists grows not only the in absolute terms, but also in relation to total employment. In fact, the share over total employment maintains an increasing tendency in the period, from 3.2% in 2011 to 4.0% in 2018. This is also reflected by higher annual growth rates of ICT specialists´ employment in comparison to total employment (Figure 10). Indeed, the ICT sector was more resilient to the economic crisis that started in 2008 than the whole economy (Mas et al., 2019). Only in 2009, when employment was strongly affected by the economic crisis, the employment of ICT specialists had negative growth, compared to four years of negative growth in total employment[15].

In 2018, the EU Member States with highest shares of ICT specialists in the labour market where Finland (7.2%), Sweden (6.8%), and Estonia (5.7%), and those with lowest shares, Greece, Romania and Latvia, slightly above 2%. In comparison with 2011, Estonia has gained eight positions, growing by 2.3 percentage points its share of ICT specialists over total employment in seven years. The United Kingdom lost three positions in the period, ranking third in 2011 and sixth in 2018 (Figure 11).

Table 8. Estimates of ICT specialists' employment in the EU (Ratio method) and Share over Total employment, 2004-2018

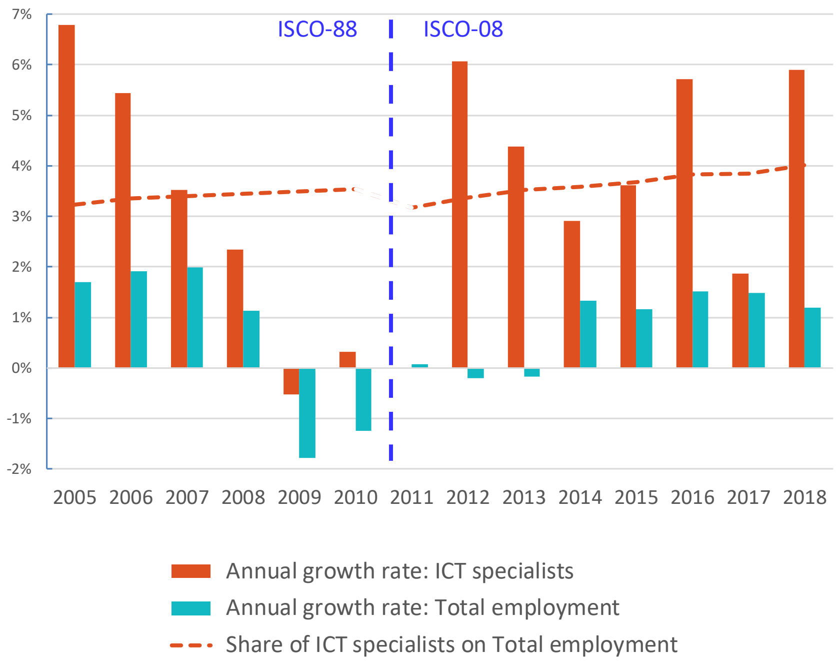
	ICT specialists (million persons)	Share over Total employment
2004	6.4	3.1%
2005	6.8	3.2%
2006	7.2	3.4%
2007	7.5	3.4%
2008	7.6	3.4%
2009	7.6	3.5%
2010	7.6	3.5%
2011	6.9	3.2%
2012	7.3	3.4%
2013	7.6	3.5%
2014	7.8	3.6%
2015	8.1	3.7%
2016	8.6	3.8%
2017	8.7	3.8%
2018	9.2	4.0%

Source: JRC estimation and Eurostat.

[14] Disregarding the break in series in 2011 due to the revision of the classification of occupations

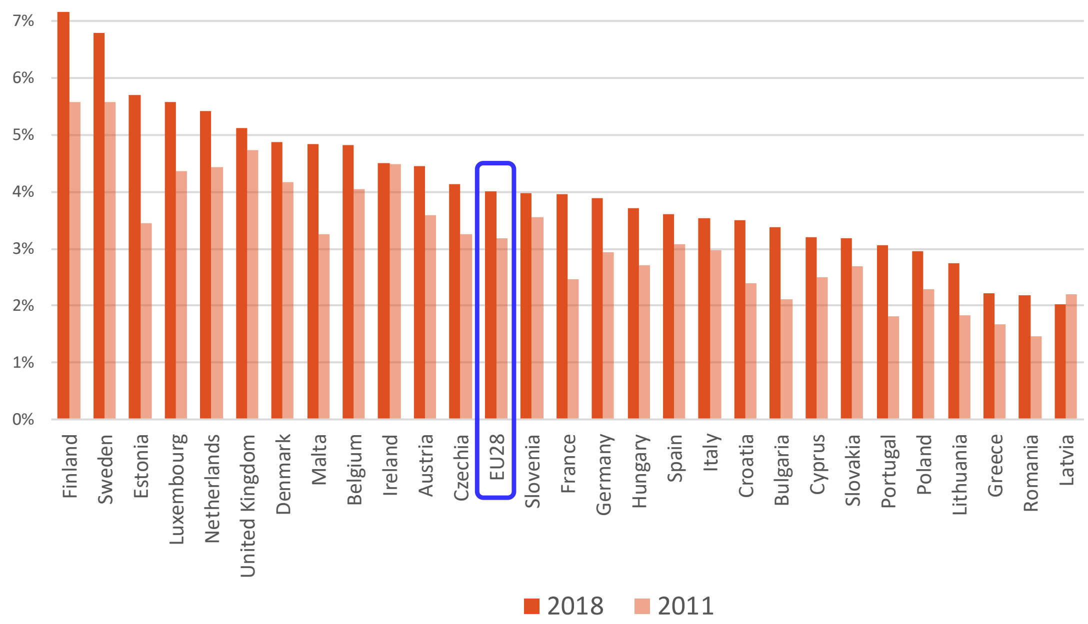
[15] The year 2011 is disregarded due to the break in the series.

Figure 10. Annual growth rate of ICT specialists´ employment and Total employment and Share of ICT specialists over Total employment, 2005-2018



Source: JRC estimation and Eurostat.

Figure 11. Share of ICT specialists over Total employment. EU Member States, 2011 and 2018



Source: JRC estimation and Eurostat.

Conclusions

The comparison of performance of the methods to estimate ICT specialists' employment in the EU and its Member States shows that the Ratio method is more accurate than the Education Filter method currently in use. This is shown in terms of lower error measures using both the Root square mean error and the Mean absolute error, and the result holds across years and occupations. All six variants of the Ratio method perform similarly well, with the best ratio reducing the error of the EF method by 35% in the period 2004-2010, and between 50% and 55% depending on the performance measure in 2011-2018, when applied to countries reporting 4d data. The removal of outliers in country-year ratios before computing the overall ratio also helps reducing the error, hence improving the final estimate.

We can also conclude that the EF method consistently underestimates the value of employment in ICT occupations. The Ratio method has a mixed behaviour, although generally found to slightly underestimate the actual employment values. The new proposed method estimates 9.2 million ICT specialists are working in the EU in 2018, 4% of total employment. This estimated number of ICT specialists is 2% higher than the value provided by the estimation method in use by Eurostat. The difference between methods reached 26% in 2004 (always with higher values for the Ratio method), and follows a decreasing trend since then due to several factors, such as lower number of countries with missing values to estimate, and lower proportion of 4d data over total ICT employment in the period 2011-2018 in comparison to 2004-2010. More importantly, the Ratio method yields more accurate estimates for countries with missing data, providing estimates higher by 34% on average in 2004-2010 and by 17% in 2011-2018, with respect to the current estimate for those countries.

In conclusion, under the assumption that employment in ICT occupations behaves similarly in the countries providing 4d data and those not providing them, the proposed imputation method produces more accurate estimates, hence allows to better monitor the evolution of ICT specialists in the labour market. According to our estimations, the number of ICT specialists in employment followed an increasing trend over the two analysed periods (2004-2010 and 2011-2018), with an overall increase of 19% in the first period, and of 35% in the second one. The share over total employment also increases, with a grow from 3.2% in 2011 to 4.0% in 2018. These results are in line with other studies that show that the ICT sector was more resilient to the economic crisis that started in 2008 then the whole economy.

Alternative methods to estimate the number of ICT specialists in employment have been considered, previously to the development of the proposed methodology. In particular, regression or clustering methods that make use of macroeconomic variables, such as supply and demand factors of employment (e.g. value added, business expenditure on R&D, students enrolled by field of education) could be developed. These might capture factors behind inter-country variation and provide more accurate estimates for countries with missing data, while at the same time facilitate the understanding of underlying labour market behaviours. However, the application of such methods, although it is very interesting from the research perspective, would hinder a quick and operational implementation, one of the objectives of this work.

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Annex

Table A. 1. RMSE by occupation for EF and Ratio methods

Period	***EF***	***Ratio r1***	***Ratio r2***	***Ratio r3***	***Ratio r4***	***Ratio r5***	***Ratio r6***	***Best method***	***% error reduction: Best method vs EF***
2004-2010 (ISCO-88)									
1236	*56.2*	***43.3***	*50.5*	*50.9*	*43.4*	*50.4*	*43.3*	*Ratio r1*	*23%*
2144	*12.3*	*10.2*	***9.5***	*9.9*	*10.2*	*9.6*	*10.3*	*Ratio r2*	*23%*
2359	*50.1*	*8.9*	*9.8*	***6.4***	*8.9*	*9.9*	*8.9*	*Ratio r3*	*87%*
3114	*10.6*	*5.7*	*5.5*	***5.2***	*5.6*	*5.6*	*5.7*	*Ratio r3*	*52%*
7242-7243	*35.9*	*29.9*	*26.0*	***25.9***	*29.8*	*26.0*	*30.1*	*Ratio r3*	*28%*
8283	*14.9*	*10.4*	***10.0***	*10.0*	*10.4*	*10.1*	*10.4*	*Ratio r2*	*33%*
2011-2018 (ISCO-08)									
2152-2153	*35.2*	*18.2*	*14.9*	*15.1*	*18.0*	***14.9***	*18.0*	*Ratio r5*	*58%*
2166	*34.5*	*6.5*	*7.6*	*7.9*	***6.4***	*7.6*	*6.9*	*Ratio r4*	*82%*
2356	*3.1*	*2.3*	*2.4*	*2.4*	***2.3***	*2.4*	*2.5*	*Ratio r4*	*28%*
2434	***9.4***	*12.6*	*10.1*	*10.1*	*12.5*	*10.1*	*12.5*	*EF*	*0%*
3114	*13.2*	*13.4*	*12.7*	***12.5***	*13.3*	*13.0*	*14.2*	*Ratio r3*	*6%*

Note: Bold font highlights the error of the best method in each row.

Source: JRC estimation.

Table A. 2. MAE by occupation for EF and Ratio methods

Period	***EF***	***Ratio r1***	***Ratio r2***	***Ratio r3***	***Ratio r4***	***Ratio r5***	***Ratio r6***	***Best method***	***% error reduction: Best method vs EF***
2004-2010 (ISCO-88)									
1236	*15.8*	***14.2***	*14.5*	*14.4*	*14.2*	*14.5*	*14.2*	*Ratio r1*	*10%*
2144	*7.6*	*5.9*	***5.7***	*5.9*	*5.9*	*5.7*	*5.9*	*Ratio r2*	*26%*
2359	*21.4*	*4.7*	*5.4*	***3.7***	*4.7*	*5.4*	*4.7*	*Ratio r3*	*83%*
3114	*7.1*	*3.5*	*3.4*	***3.2***	*3.5*	*3.5*	*3.5*	*Ratio r3*	*55%*
7242-7243	*17.4*	*14.6*	*11.6*	***11.6***	*14.5*	*11.7*	*14.7*	*Ratio r3*	*33%*
8283	*8.6*	*6.1*	***5.9***	*5.9*	*6.1*	*5.9*	*6.0*	*Ratio r2*	*32%*
2011-2018 (ISCO-08)									
2152-2153	*18.2*	*7.4*	***7.0***	*7.0*	*7.4*	*7.0*	*7.5*	*Ratio r2*	*61%*
2166	*18.6*	*3.4*	*4.2*	*4.3*	***3.4***	*4.2*	*3.7*	*Ratio r4*	*82%*
2356	*1.4*	*1.1*	*1.1*	*1.1*	***1.1***	*1.1*	*1.1*	*Ratio r4*	*21%*
2434	***4.1***	*5.6*	*4.8*	*4.7*	*5.5*	*4.8*	*5.5*	*EF*	*0%*
3114	*6.9*	*5.8*	*5.3*	***5.1***	*5.7*	*5.4*	*6.0*	*Ratio r3*	*27%*

Note: Bold font highlights the error of the best method in each row.

Source: JRC estimation.

Table A. 3. RMSE by year for EF and Ratio methods

Period	**EF**	**Ratio r1**	**Ratio r2**	**Ratio r3**	**Ratio r4**	**Ratio r5**	**Ratio r6**	**Best method**	**% error reduction: Best method vs EF**
2004-2010 (ISCO-88)									
2004	*33.5*	*21.3*	*22.6*	*22.6*	***21.3***	*24.4*	*22.4*	*Ratio r4*	*37%*
2005	*33.4*	***22.0***	*23.4*	*23.4*	*22.0*	*25.2*	*22.3*	*Ratio r1*	*34%*
2006	*36.2*	***23.9***	*25.5*	*25.4*	*23.9*	*26.0*	*24.2*	*Ratio r1*	*34%*
2007	*36.1*	*23.4*	*25.1*	*25.1*	*23.5*	*24.4*	***23.3***	*Ratio r6*	*36%*
2008	*35.5*	*22.6*	*24.1*	*24*	*22.6*	*23.6*	***22.2***	*Ratio r6*	*37%*
2009	*35.2*	*23.0*	*24.8*	*24.7*	*23.0*	*22.7*	***22.4***	*Ratio r6*	*36%*
2010	*36.1*	*22.8*	*24.5*	*24.3*	*22.8*	*23.6*	***22.5***	*Ratio r6*	*38%*
2011-2018 (ISCO-08)									
2011	*23.1*	*11.1*	*10.9*	*11.1*	*11.1*	*10.8*	***10.7***	*Ratio r6*	*54%*
2012	*21.5*	*12.5*	***11.3***	*11.3*	*12.4*	*11.7*	*12.7*	*Ratio r2*	*48%*
2013	*20.7*	*11.4*	*9.4*	***9.4***	*11.3*	*9.9*	*11.7*	*Ratio r3*	*55%*
2014	*21.9*	*12.0*	*10.1*	*10.1*	*11.9*	***10.0***	*12.5*	*Ratio r5*	*54%*
2015	*23.2*	*11.3*	*9.8*	***9.8***	*11.2*	*9.8*	*11.2*	*Ratio r3*	*58%*
2016	*24.2*	*12.0*	*10.4*	*10.4*	*11.8*	***10.0***	*12.0*	*Ratio r5*	*59%*
2017	*24.3*	*12.5*	***10.6***	*10.7*	*12.4*	*10.7*	*12.9*	*Ratio r2*	*56%*
2018	*26*	*12.8*	***11.2***	*11.3*	*12.6*	*11.4*	*13.1*	*Ratio r2*	*57%*

Note: Bold font highlights the error of the best method in each row.

Source: JRC estimation.

Table A. 4. MAE by year for EF and Ratio methods

Period	**EF**	**Ratio r1**	**Ratio r2**	**Ratio r3**	**Ratio r4**	**Ratio r5**	**Ratio r6**	**Best method**	**% error reduction: Best method vs EF**
2004-2010 (ISCO-88)									
2004	*12.7*	*7.9*	*7.6*	***7.3***	*7.9*	*7.8*	*8.2*	*Ratio r3*	*42%*
2005	*12.2*	*7.8*	*7.4*	***7.2***	*7.8*	*7.8*	*7.8*	*Ratio r3*	*41%*
2006	*12.9*	*8.3*	*7.9*	***7.6***	*8.3*	*8.1*	*8.4*	*Ratio r3*	*41%*
2007	*13.5*	*8.5*	*8.0*	***7.7***	*8.5*	*7.8*	*8.5*	*Ratio r3*	*43%*
2008	*13.5*	*8.4*	*7.9*	***7.6***	*8.4*	*8.0*	*8.3*	*Ratio r3*	*44%*
2009	*13.1*	*8.1*	*7.7*	***7.4***	*8.1*	*7.5*	*8.0*	*Ratio r3*	*44%*
2010	*12.9*	*8.1*	*7.7*	***7.4***	*8.1*	*7.5*	*7.9*	*Ratio r3*	*43%*
2011-2018 (ISCO-08)									
2011	*7.7*	***4.2***	*4.2*	*4.3*	*4.2*	*4.3*	*4.3*	*Ratio r1*	*46%*
2012	*8.7*	*5.1*	***5.1***	*5.1*	*5.1*	*5.4*	*5.2*	*Ratio r2*	*42%*
2013	*9.0*	*4.2*	*3.9*	***3.9***	*4.2*	*4.2*	*4.3*	*Ratio r3*	*57%*
2014	*9.5*	*4.5*	*4.1*	***4.1***	*4.4*	*4.2*	*4.7*	*Ratio r3*	*57%*
2015	*9.8*	*4.3*	*4.1*	***4.0***	*4.2*	*4.1*	*4.3*	*Ratio r3*	*59%*
2016	*10.4*	*4.6*	*4.5*	*4.4*	*4.6*	***4.2***	*4.8*	*Ratio r5*	*59%*
2017	*11.2*	*4.9*	*4.7*	*4.7*	*4.9*	***4.6***	*5.0*	*Ratio r5*	*59%*
2018	*11.9*	*5.3*	*5.2*	*5.1*	*5.3*	***5.0***	*5.4*	*Ratio r5*	*58%*

Note: Bold font highlights the error of the best method in each row.

Source: JRC estimation.

Table A. 5. Estimates of ICT specialists' employment in the EU by method, 2004-2018 (thousand persons)

Year	**EF estimation**	**Ratio estimation**	**Difference**	
			Ratio - EF	**(Ratio - EF)/EF (%)**
2004	5086.2	6411.3	1325.1	26%
2005	5522.2	6845.9	1323.7	24%
2006	5867.0	7218.3	1351.3	23%
2007	6142.4	7472.7	1330.3	22%
2008	6265.6	7648.0	1382.4	22%
2009	6301.4	7608.6	1307.2	21%
2010	6301.3	7633.4	1332.1	21%
2011	6401.5	6854.2	452.7	7%
2012	6970.8	7269.4	298.6	4%
2013	7296.8	7588.5	291.7	4%
2014	7493.0	7809.5	316.5	4%
2015	7754.6	8091.3	336.7	4%
2016	8241.2	8554.4	313.2	4%
2017	8560.5	8714.9	154.4	2%
2018	9068.6	9229.0	160.4	2%

Note: Estimates with the EF method may slightly differ from the official data published due to lack of access to cells with confidential data ('c' flag).

Source: JRC estimation.

Table A. 6. Differences between Ratio and EF methods' estimates of ICT specialists by Member State, 2004-2018 (%)

	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Belgium	24%	28%	27%	28%	30%	30%	26%	12%							
Bulgaria	46%	44%	46%	46%	47%	41%	38%	14%	17%	11%	17%	12%	14%	12%	10%
Denmark	29%	28%	29%	28%	28%	28%	25%	12%	12%	13%	15%	14%	14%	14%	14%
Germany	34%	32%	33%	30%	31%	30%	30%	12%							
Ireland	46%	45%	55%	45%	41%	36%	37%								
Greece	64%	65%	64%	61%	60%	54%	54%	25%	24%	20%	23%	24%	25%	21%	19%
Spain	42%	38%	31%	27%	27%	26%	27%	13%	15%	15%	14%	19%	11%	12%	11%
France	42%	37%	37%	39%	39%	34%	36%								
Italy	29%	28%	26%	26%	26%	27%	27%	22%	22%	21%	22%	23%	22%		
Cyprus	31%	33%	31%	31%	31%	33%	34%	18%	18%	16%	15%				
Latvia	46%	40%	40%	45%	46%	42%	34%	6%	10%	10%	11%	12%	11%	9%	17%
Portugal	45%	44%	43%	43%	47%	47%	48%	31%	26%	22%	20%	21%	23%	24%	24%

Note: Countries that need imputation of 4d employment at least one year. Empty cells are not subject to imputation, since 4d data are reported for those years.

Source: JRC estimation.

Table A. 7. Error of EF method applied to reporting countries by country and occupation, 2004-2010 (%)

	2004	2005	2006	2007	2008	2009	2010
	1236: Computing services managers						
Czechia	-100%	-100%	-40%	-58%	-85%	-73%	-48%
Estonia	0%	-49%	0%	66%	-17%	20%	-71%
Croatia	0%	0%	-100%	-100%	54%	-6%	-100%
Lithuania	0%	*c*	132%	12%	78%	-5%	2%
Luxembourg	105%	-22%	150%	-62%	-89%	-49%	194%
Hungary	-22%	21%	-48%	-60%	-37%	-36%	-30%
Malta	0%	*c*	-19%	-40%	-14%	-37%	-40%
Netherlands	-77%	-73%	-63%	-63%	-62%	-74%	-67%
Austria	-45%	-66%	-81%	-19%	3%	165%	-69%
Poland	-87%	-59%	-32%	0%	4%	-9%	1%
Romania	*c*	2175%	26%	-18%	-33%	32%	119%
Slovenia	*c*	-100%	-90%	-72%	-37%	-64%	-43%
Slovakia	*c*	-88%	-100%	-100%	-100%	-87%	-100%
Finland	-62%	-68%	-74%	-82%	-76%	-66%	-80%
Sweden	-79%	-84%	-82%	-67%	-58%	-67%	-74%
United Kingdom	-79%	-78%	-79%	-78%	-77%	-73%	-73%
	2144: Electronics and telecommunications engineers						
Czechia	-100%	-100%	-92%	-100%	-78%	-97%	-97%
Estonia	-42%	-94%	-100%	-73%	-84%	-80%	-76%
Croatia	-100%	-50%	-88%	-78%	-84%	-100%	-100%
Lithuania	-89%	-94%	-97%	-92%	-14%	-78%	-76%
Luxembourg	-89%	-92%	-92%	-93%	-100%	-92%	-81%
Hungary	-91%	-75%	-75%	-75%	-75%	-72%	-84%
Malta	0%	*c*	-67%	-86%	-100%	-92%	-85%
Netherlands	-59%	-49%	-24%	11%	-21%	-29%	22%
Austria	-86%	-87%	-72%	-74%	-73%	-59%	-31%
Poland	-95%	-78%	-86%	-81%	-71%	-82%	-81%
Romania	*c*	-63%	-66%	-60%	-57%	-73%	-78%
Slovenia	-100%	-90%	-91%	-82%	-80%	-72%	-72%
Slovakia	-58%	-85%	-51%	-57%	-79%	-91%	-89%
Finland	-96%	-96%	-96%	-93%	-91%	-90%	-93%
Sweden	-99%	-98%	-96%	-92%	-94%	-95%	-90%
United Kingdom	-93%	-86%	-73%	-84%	-82%	-89%	-80%
	2359: Information technology trainers						
Czechia	-100%	-100%	-100%	-99%	-99%	-100%	-100%
Estonia	-100%	-97%	-99%	-100%	-95%	-99%	-100%
Croatia	-100%	-100%	-100%	-100%	-100%	-100%	-100%
Lithuania	-100%	-100%	-100%	-96%	-100%	-85%	-100%
Luxembourg	-100%	-100%	-100%	-100%	-100%	-93%	-100%

Hungary	-100%	-100%	-99%	-100%	-99%	-99%	-99%
Malta	*c*	0%	-100%	-100%	-100%	-100%	-100%
Netherlands	-100%	-94%	-95%	-100%	-100%	-95%	-100%
Austria	-100%	-99%	-97%	-98%	-99%	-98%	-99%
Poland	-100%	-99%	-100%	-100%	-100%	-100%	-99%
Romania	*c*	-89%	-100%	-100%	-100%	-100%	-100%
Slovenia	-100%	-100%	-98%	-100%	-100%	-100%	-100%
Slovakia	-100%	-100%	-99%	-97%	-100%	-100%	-100%
Finland	-100%	-91%	-82%	-90%	-97%	-74%	-84%
Sweden	-100%	-98%	-100%	-100%	-99%	-99%	-100%
United Kingdom	-99%	-99%	-99%	-98%	-98%	-99%	-98%
	3114: Electronics and telecommunications engineering technicians						
Czechia	-100%	-100%	-91%	-96%	-95%	-88%	-93%
Estonia	-100%	-98%	-100%	-100%	-90%	-71%	-100%
Croatia	-100%	-96%	-100%	-88%	-85%	-89%	-92%
Lithuania	-100%	-70%	-100%	-100%	-100%	-100%	-97%
Luxembourg	-93%	-100%	-100%	-63%	-100%	-73%	-73%
Hungary	-50%	-50%	-27%	-39%	-72%	-29%	-16%
Malta	*c*	*c*	-97%	-94%	-91%	-92%	-86%
Netherlands	-55%	-36%	-33%	-41%	-38%	11%	66%
Austria	-91%	-92%	-96%	-97%	-98%	-94%	-89%
Poland	-100%	-79%	-70%	-85%	-85%	-71%	-69%
Romania	*c*	-81%	-75%	-76%	-80%	-89%	-82%
Slovenia	-100%	-100%	-100%	-100%	-83%	-90%	-100%
Slovakia	-100%	-98%	-88%	-88%	-95%	-100%	-95%
Finland	-92%	-91%	-93%	-97%	-96%	-85%	-83%
Sweden	-98%	-98%	-91%	-93%	-94%	-91%	-93%
United Kingdom	-82%	-84%	-61%	-86%	-81%	-85%	-78%
	7242, 7243: Electronics fitters, Electronics mechanics and servicers						
Czechia	-100%	-100%	-100%	-99%	-99%	-98%	-97%
Estonia	-100%	-100%	-100%	-99%	-99%	-99%	-100%
Croatia	-100%	-95%	-100%	-100%	-100%	-100%	-100%
Lithuania	-100%	-100%	-98%	-99%	-100%	-99%	-95%
Luxembourg	-100%	-100%	-100%	-100%	-94%	-100%	-100%
Hungary	-98%	-98%	-97%	-99%	-95%	-95%	-98%
Malta	0%	*c*	-85%	-99%	-100%	-100%	-100%
Netherlands	-94%	-97%	-93%	-92%	-93%	-89%	-87%
Austria	-100%	-100%	-99%	-99%	-99%	-100%	-100%
Poland	-100%	-89%	-87%	-92%	-94%	-95%	-91%
Romania	*c*	-84%	-83%	-86%	-88%	-88%	-74%
Slovenia	-100%	-100%	-100%	-100%	-100%	-100%	-100%
Slovakia	-100%	-95%	-92%	-90%	-95%	-100%	-98%

Finland	-100%	-100%	-96%	-97%	-98%	-98%	-98%
Sweden	-100%	-99%	-99%	-99%	-99%	-98%	-98%
United Kingdom	-92%	-92%	-91%	-94%	-94%	-90%	-92%
	8283: Electronic-equipment assemblers						
Czechia	-100%	-100%	-99%	-99%	-99%	-100%	-100%
Estonia	-100%	-99%	-99%	-99%	-92%	-93%	-97%
Croatia	-100%	-100%	-100%	-100%	-55%	1%	4%
Lithuania	-100%	-100%	-100%	-100%	-70%	-66%	-88%
Luxembourg	-100%	-100%	-100%	-100%	-100%	-100%	-100%
Hungary	-100%	-99%	-98%	-99%	-99%	-99%	-98%
Malta	0%	0%	-100%	-99%	-100%	-96%	-99%
Netherlands	-73%	2%	-87%	-71%	-64%	14%	-100%
Austria	-100%	-100%	-100%	-98%	-91%	-100%	-100%
Poland	-100%	-94%	-87%	-88%	-91%	-95%	-94%
Romania	c	-92%	-92%	-92%	-97%	-96%	-88%
Slovenia	-100%	-99%	-100%	-100%	-100%	-100%	-100%
Slovakia	-100%	-100%	-100%	-99%	-99%	-100%	-99%
Finland	-97%	-100%	-100%	-97%	-100%	-86%	-100%
Sweden	*c*	*c*	*c*	*c*	*c*	*c*	*c*
United Kingdom	*c*	*c*	*c*	*c*	*c*	*c*	0%

Note: The percent error is measured as the percentage of the estimation error (EF method - Actual value) over the Actual value.

Source: JRC estimation and LFS.

Table A. 8. Error of EF method applied to reporting countries by country and occupation, 2011-2018 (%)

	2011	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
	2152, 2153: Electronic engineers, Telecommunication engineers							
Belgium	-	-83%	-91%	-96%	-99%	-90%	-88%	-86%
Czechia	-74%	-95%	-94%	-84%	-89%	-88%	-100%	-76%
Germany	-	-85%	-83%	-90%	-95%	-90%	-90%	-90%
Estonia	-92%	*-85%*	-100%	-92%	-93%	-96%	-86%	-97%
Ireland	-100%	-100%	-100%	-100%	-100%	-100%	-100%	-100%
France	-74%	-82%	-78%	-83%	-85%	-98%	-97%	-93%
Croatia	-89%	*-83%*	-50%	-84%	-100%	-100%	-100%	-100%
Italy	-	-	-	-	-	-	-95%	-94%
Cyprus	-	-	-	-	-100%	-100%	-100%	-100%
Lithuania	-86%	-85%	-96%	-97%	-100%	-100%	-93%	-97%
Luxembourg	*-93%*	-91%	-93%	-96%	-87%	-100%	-93%	-100%
Hungary	*-86%*	-79%	-85%	-85%	-86%	-83%	-92%	-95%
Malta	*-100%*	-100%	-65%	-84%	-95%	-93%	-67%	-47%
Netherlands	*-92%*	-100%	-80%	-92%	-99%	-94%	-87%	-91%

Austria	*-70%*	-79%	-86%	-85%	-92%	-85%	-84%	-86%
Poland	*-95%*	-95%	-92%	-90%	-77%	-75%	-81%	-80%
Romania	*-90%*	-90%	-87%	-96%	-93%	-94%	-90%	-87%
Slovenia	*-98%*	-100%	-97%	-97%	-96%	-94%	-90%	-97%
Slovakia	*-95%*	-100%	-93%	-79%	-100%	-100%	-100%	-100%
Finland	-89%	-89%	-93%	-97%	-95%	-71%	-79%	-71%
Sweden	-97%	-97%	-96%	-99%	-97%	-99%	-99%	-100%
United Kingdom	-98%	-99%	-97%	-97%	-99%	-99%	-99%	-99%
	2166: Graphic and multimedia designers							
Belgium	-	-99%	-94%	-96%	-98%	-97%	-97%	-100%
Czechia	-100%	-100%	-88%	-100%	-89%	-100%	-100%	-90%
Germany	-	-94%	-94%	-95%	-95%	-96%	-95%	-95%
Estonia	-100%	*-94%*	-82%	-89%	-100%	-93%	-88%	-98%
Ireland	-100%	-100%	-100%	-100%	-100%	-100%	-100%	-100%
France	0%	c	-94%	-96%	-97%	-96%	-98%	-97%
Croatia	-94%	*-82%*	-93%	-100%	-100%	-100%	-78%	-66%
Italy	-	-	-	-	-	-	-97%	-97%
Cyprus	-	-	-	-	-100%	-100%	-100%	-100%
Lithuania	-93%	-82%	-95%	-100%	-97%	-75%	-78%	-78%
Luxembourg	*-100%*	-100%	-100%	-100%	-93%	-89%	-82%	-89%
Hungary	*-86%*	-96%	-93%	-93%	-99%	-86%	-84%	-98%
Malta	*0%*	23%	-100%	-87%	-81%	-77%	-87%	-100%
Netherlands	*-92%*	-93%	-91%	-92%	-89%	-97%	-96%	-95%
Austria	*-100%*	-98%	-97%	-95%	-97%	-98%	-99%	-97%
Poland	*-80%*	-86%	-84%	-78%	-74%	-78%	-81%	-76%
Romania	*-32%*	-66%	-50%	-78%	-77%	-76%	-100%	-93%
Slovenia	*-94%*	-90%	-100%	-94%	-89%	-90%	-98%	-98%
Slovakia	*-100%*	-90%	-70%	-87%	-79%	-83%	-100%	-99%
Finland	-96%	-92%	-100%	-100%	-100%	-89%	-90%	-92%
Sweden	-94%	-96%	-94%	-91%	-92%	-92%	-93%	-93%
United Kingdom	-97%	-97%	-93%	-98%	-97%	-98%	-96%	-98%
	2356: Information technology trainers							
Belgium	-	-83%	-83%	-93%	-100%	-100%	-81%	-100%
Czechia	-53%	-100%	0%	-100%	-72%	-100%	-69%	-100%
Germany	-	-82%	-85%	-89%	-86%	-91%	-94%	-77%
Estonia	-100%	*25%*	106%	-100%	-100%	-100%	-100%	-100%
Ireland	0%	0%	0%	0%	0%	0%	0%	0%
France	-	-	-62%	-100%	-39%	-100%	-100%	-90%
Croatia	0%	*0%*	0%	0%	0%	0%	0%	0%
Italy	-	-	-	-	-	-	c	c
Cyprus	-	-	-	-	-67%	-40%	0%	0%
Lithuania	0%	-100%	0%	0%	0%	130%	124%	108%

Luxembourg	*-57%*	109%	67%	212%	3%	-19%	-100%	c
Hungary	*0%*	-100%	-17%	-25%	0%	c	c	0%
Malta	*0%*	c	-100%	-44%	-37%	111%	333%	-100%
Netherlands	*c*	124%	-55%	-62%	-46%	-100%	-94%	-88%
Austria	*-95%*	-100%	-93%	-92%	-83%	-70%	-69%	-83%
Poland	*223%*	-61%	-58%	100%	c	c	-51%	-75%
Romania	*c*	c	0%	0%	0%	-100%	-80%	-58%
Slovenia	*-100%*	0%	353%	188%	c	-100%	60%	c
Slovakia	*-100%*	-100%	-100%	-100%	-100%	-100%	-100%	0%
Finland	-74%	-35%	282%	-16%	-75%	85%	-61%	-100%
Sweden	-84%	-89%	-85%	-79%	-81%	-52%	-34%	-76%
United Kingdom	-81%	-57%	-76%	-75%	-75%	-94%	-84%	-91%
	2434: ICT sales professionals							
Belgium	-	-41%	-97%	-90%	-86%	-77%	-93%	-66%
Czechia	-45%	-73%	-62%	-87%	-100%	-45%	-73%	-95%
Germany	-	-46%	-50%	-64%	-61%	-63%	-57%	-58%
Estonia	-100%	*-87%*	-100%	-100%	-100%	0%	-100%	-69%
Ireland	0%	0%	0%	0%	0%	0%	0%	0%
France	-83%	-81%	-79%	-77%	-88%	-89%	-88%	-92%
Croatia	0%	*-100%*	-100%	-100%	-100%	-100%	-100%	-78%
Italy	-	-	-	-	-	-	-96%	-99%
Cyprus	-	-	-	-	-100%	-100%	-84%	-98%
Lithuania	181%	54%	72%	368%	-49%	8%	-71%	-57%
Luxembourg	*-100%*	-71%	-52%	-100%	-92%	-36%	-9%	46%
Hungary	*57%*	-83%	-37%	-92%	-83%	-21%	-45%	-42%
Malta	*0%*	0%	0%	c	0%	c	c	c
Netherlands	*c*	272%	-55%	-59%	-73%	-75%	-78%	-86%
Austria	*-94%*	-48%	-82%	-2%	-77%	-100%	-78%	-27%
Poland	*-48%*	-45%	-37%	-2%	23%	-4%	139%	37%
Romania	*47%*	-40%	57%	-12%	11%	-100%	-71%	-70%
Slovenia	*-41%*	-100%	-100%	-100%	-100%	-100%	-100%	-60%
Slovakia	*-52%*	-62%	-67%	-86%	-100%	-78%	-69%	-74%
Finland	-46%	-70%	-76%	-86%	-90%	-93%	-82%	-85%
Sweden	-54%	-52%	-56%	-56%	-60%	-68%	-91%	-70%
United Kingdom	64%	-3%	15%	-2%	47%	33%	26%	67%
	3114: Electronics engineering technicians							
Belgium	-	-92%	-94%	-94%	-87%	-95%	-72%	-94%
Czechia	-91%	-90%	-93%	-73%	-72%	-84%	-93%	-88%
Germany	-	-47%	-39%	-65%	-44%	-71%	-60%	-68%
Estonia	-100%	*-35%*	-73%	-100%	-93%	-21%	-72%	-100%
Ireland	0%	0%	0%	0%	0%	0%	0%	0%
France	-27%	-45%	-74%	-93%	-93%	-96%	-81%	-83%

Croatia	-80%	*-91%*	-100%	-100%	-100%	-64%	-66%	-100%
Italy	-	-	-	-	-	-	-95%	-95%
Cyprus	-	-	-	-	-92%	-87%	-78%	-82%
Lithuania	-92%	-100%	-75%	90%	-25%	-83%	-94%	-61%
Luxembourg	*-97%*	-92%	-100%	-100%	-89%	-100%	-100%	-100%
Hungary	*-67%*	-65%	-48%	-85%	-90%	-73%	-92%	-85%
Malta	*-63%*	-74%	-81%	-81%	-92%	-93%	-82%	-81%
Netherlands	*-80%*	-84%	-85%	-81%	-93%	-94%	-90%	-77%
Austria	*-98%*	-93%	-90%	-96%	-96%	-97%	-87%	-90%
Poland	*-80%*	-76%	-85%	-84%	-79%	-78%	-83%	-75%
Romania	*-74%*	-87%	-81%	-88%	-87%	-92%	-100%	-96%
Slovenia	*-91%*	-100%	-100%	-86%	-50%	-69%	-90%	-82%
Slovakia	*-78%*	-92%	-74%	-100%	-100%	-96%	-18%	-85%
Finland	-81%	-83%	-82%	-93%	-94%	-78%	-65%	-69%
Sweden	-90%	-90%	-89%	-95%	-94%	-96%	-96%	-95%
United Kingdom	-77%	-64%	-68%	-95%	-68%	-85%	-41%	-64%

Note: The percent error is measured as the percentage of the estimation error (EF method - Actual value) over the Actual value

Source: JRC estimation and LFS.

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Information about the European Union in all the official languages of the EU is available on the Europa website at: https://europa.eu/european-union/index_en

EU publications

You can download or order free and priced EU publications from EU Bookshop at: https://publications.europa.eu/en/publications. Multiple copies of free publications may be obtained by contacting Europe Direct or your local information centre (see https://europa.eu/european-union/contact_en).

GETTING IN TOUCH WITH THE EU

In person

All over the European Union there are hundreds of Europe Direct information centres. You can find the address of the centre

The European Commission's science and knowledge service

Joint Research Centre

JRC Mission

As the science and knowledge service of the European Commission, the Joint Research Centre's mission is to support EU policies with independent evidence throughout the whole policy cycle.

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