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Jan A. Baran – Narodowy Bank Polski & University of Warsaw, Faculty of Economic Sciences;
jan.baran@nbp.pl

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Contents

Abstract

The paper investigates changes in the quality of the labour input in Poland in 2006-2020. Labour quality – which captures compositional changes of the workforce, referring to education, experience, gender and occupation – substantially improved, growing on average by 0.55% a year, compared to much slower growth of unadjusted labour input (hours worked) of 0.11% a year. Growth in the labour quality, which means improvement in workers' characteristics, was mainly driven by positive changes in the educational composition of workers. Labour quality growth showed less volatility compared to growth of hours worked in the economy and it was negatively correlated to both growth of hours worked and GDP growth, mitigating procyclicality of the labour input. Additionally, falling tertiary education wage premia are documented.

Keywords: human capital, labour quality, labour input.

JEL codes: E24, J21, J24.

1 Introduction

Traditionally, the labour input has been measured as the number of people working or number of hours worked in the economy. However, such a measure overlooks changes in the quality of the labour input due to the changing composition of workers' characteristics. For instance, an increase in the number of university graduates among workers, which many European countries experienced over the last decades, means a positive change in the employment composition and is likely to translate into higher average productivity. Not addressing the labour quality improvement leads to a downward bias of the labour input and consequently exaggerates the contribution of TFP to GDP growth.

An analysis of the labour quality change in Poland is of particular interest due to the educational boom. Over last three decades, Poland's tertiary enrolment rates increased from around 10% in the early 1990s to about 50% recently. It translated into a substantial improvement in the educational composition of the workforce. In 2006-2020, the share of tertiary educated workers in total employment grew from 22% to 37%, the share of workers holding upper secondary education fell from 68% to 58%, whilst the share of workers with primary or lower secondary education decreased from 9% to 5%.

In the paper I investigate the change in quality of the labour input in Poland in 2006-2020, examine the factors behind this change and look at gender, regional and sectoral differences in labour quality. The quality of the labour input is calculated by comparing the quality-adjusted labour input and the unadjusted labour input. Detailed microdata from the Polish Labour Force Survey are used. Unlike other similar studies which use age as a proxy for workers' experience, I use work experience directly reported by respondents. The paper documents a substantial improvement in labour quality, which was driven by change in the educational and occupational composition of the workforce. As an additional finding, the estimates of the Mincerian wage equation, which are used to obtain weights for the labour quality calculation, show a sizeable fall in the wage premia associated with tertiary education over 2006-2020.

The rest of the paper is organised as follows. Section 2 discusses the literature on measuring labour quality. Section 3 presents the methodology and describes the data used in this paper. Section 4 reports the descriptive statistics showing the improving structure of Poland's workforce. Section 5 reports the results for an estimation of the augmented Mincerian wage equation. Section 6 presents the results of the calculations of the change in quality of the labour input with decomposition and robustness checks. The final section concludes.

2 Literature

The notion of labour quality is closely related to human capital. Human capital consists of workers' knowledge, skills and health affecting their productivity. It has played a prominent role in economic theory since Becker (1964) and is listed as one of the main factors of production along with physical capital and labour. Human capital is also claimed to be a key source of economic growth in the works of Romer (1986) and Lucas (1988). In line with the human capital perspective, labour quality quantifies an aggregate indicator of productivity-related characteristics of workers. In the first step, productivity-related weights are assigned to different groups of workers to obtain the quality-adjusted labour input. Then, the difference between the quality-adjusted and unadjusted labour input, i.e. hours worked, produces a labour quality indicator. The key assumption behind measuring labour quality is the standard neoclassical assumption stating that a worker is renumerated according to his or her productivity. Hence, wage differentials between workers should reflect productivity differences, stemming from differences in human capital endowments. Based on this, labour quality can be seen as an aggregate measure of human capital.

A seminal early attempt to measure the quality-adjusted labour input and labour quality in the US was presented in a book by Jorgenson et al. (1987), who used shares of different types of workers in total compensation as productivity-linked weights. A different methodology was introduced by the US Bureau of Labor Statistics (1993). Instead of taking simple shares in compensation of employees, they used predicted wages from wage regression estimated on microdata. This approach to computing weights became dominant in more recent studies. Other studies quantifying labour quality changes for the US are Aaronson and Sullivan (2001), Zoghi (2010), or more recent work by Bosler et al. (2017). In Europe, studies were conducted inter alia for the euro area (Schwerdt and Turunen, 2007), the United Kingdom (Bell, Burriel-Llombart, and Jones, 2005; Dey-Chowdhury and Goodridge, 2007), Italy (Baldassarini and di Veroli, 2009), Switzerland (Bolli and Zurlinden, 2009), Ireland (Keeney, 2010), the Spain

(Lacuesta et al., 2011). Previous attempts to measure labour quality for Poland were done by Kolasa and Strzelecki (2007) and Gradzewicz et al. (2018).[1] Additionally, Aaronson and Sullivan (2001) and Bolli and Zurlinden (2009) investigate labour quality of the unemployed.

Calculation of the productivity-linked weights plays a central role in quality adjustment. The most popular set of characteristics used for quality adjustment includes education, age and gender (Aaronson and Sullivan, 2001; Bell et al., 2005; Schwerdt and Turunen, 2007; Kolasa and Strzelecki, 2007; Baldassarini and di Veroli, 2009; Keeney, 2010). It resembles the analogy to the Mincerian wage equation (Mincer, 1974), which explains a worker's wage by education represented by the number of years of schooling and experience proxied by age. Age should be included in non-linear form to reflect the inverted U-shaped relationship between age and wages.[2] Including gender distinction in the quality adjustment reflects significant wage differentials between males and females.[3] However, the set of the three abovementioned variables is not exclusionary nor unchangeable. For instance, Bosler et al. (2017) investigate an augmented set of variables consisting of age, education, gender, race, industry and occupation. Justified by observed wage differentials, the set of variables used for quality adjustment is sometimes extended further to cover job characteristics such as part-time/full-time employment or sector of economic activity, in either a main analysis or for the purpose of the robustness analysis (Schwerdt and Turunen, 2007; Zoghi, 2010; Bosler et al., 2017).[4] However, calculations using a broader

[1] Strzelecki, Growiec, and Wyszyński (2022) also measure labour quality in Poland, but they mainly focus on contribution of migrant workers to economic growth in Poland.

[2] Usually, wages increase with age, initially rapidly and then at declining rate, eventually they reach the maximum, and finally stabilise or decline for older workers. The inverted U-shaped pattern of the age-earnings profile can be recreated theoretically under the Ben-Porath model of human capital (Ben-Porath, 1967).

[3] On the other hand, including the gender dimension for the quality adjustment is controversial, as factors included in the adjustment should reflect differences in workers' productivity. However, there is a debate to what extent the male-female wage differentials actually reflect productivity differentials between genders and to what extent they are a consequence of discrimination.

[4] Nevertheless, Schwerdt and Turunen (2007) point out that it is not clear what the relationship is of such variables as working part-time/full-time or sector of economic activity with human capital, which calls into question whether it is correct to use them for quality adjustment.

scope of variables usually give similar results as more parsimonious ones (Schwerdt and Turunen, 2007; Zoghi, 2010), especially qualitatively when referring to the pattern of change (Bosler et al., 2017).

Previous studies for developed countries show substantial expansion of labour quality over the last decades. Aaronson and Sullivan (2001) report that labour quality in the US grew on average by 0.33% a year in 1964-2000, following the inverted U-shaped path, with the 1980s to mid-1990s experiencing the fastest labour quality growth rates. According to Schwerdt and Turunen (2007) labour quality growth in the euro area was on average 0.47% a year in 1983-2005, with a similar inverted U-shaped path as in the US, with the highest growth rates in the early 1990s. Further calculations by Bosler et al. (2017) show that US labour quality grew by 0.5% a year in 2002-2013. For Poland, Kolasa and Strzelecki (2007) calculate labour quality growth of 0.9% a year in 1993-2006. Gradzewicz et al. (2018) report consistently positive growth of labour quality in 1995-2013 of 1.2% a year on average and demonstrate that taking into account changes in the labour quality overturns negative developments of the unadjusted labour input in the late 1990s and early 2000s. Also studies for other countries show significant improvements in labour quality (Bell et al., 2005; Dey-Chowdhury and Goodridge, 2007; Baldassarini and di Veroli, 2009; Bolli and Zurlinden, 2009; Keeney, 2010; Schwerdt and Turunen, 2010; Lacuesta et al., 2011). Furthermore, the studies agree that the main driver behind the labour quality changes was the improvement in the educational composition of the workforce (Aaronson and Sullivan, 2001; Bell et al., 2005; Kolasa and Strzelecki, 2007; Schwerdt and Turunen, 2007; Baldassarini and di Veroli, 2009; Bolli and Zurlinden, 2009; Keeney, 2010; Schwerdt and Turunen, 2010; Gradzewicz et al., 2018).

3 Methodology and data

3.1 Labour quality index

In general, the quality of the labour input is calculated by comparing the quality-adjusted labour input and unadjusted labour input. The quality-adjusted labour input is a weighted sum of hours worked in the economy, where weights are assumed to reflect workers' productivity, whilst the unadjusted labour input is the number of total hours worked.

For calculations of labour quality, I follow the approach from Aaronson and Sullivan (2001). They calculate the growth rate of the quality of labour input at time t as a geometric mean of two subindices, each of them representing the change of weighted the sum of hours worked in the economy (change in quality-adjusted labour input) divided by the change in the unweighted number of hours (change in unadjusted labour input). The formula for the first subindex is:

$$dQ_t^0 = \frac{\sum_i \left(\widehat{w}_i^{t-1} \frac{H_{i,t}}{H_t}\right)}{\sum_i \left(\widehat{w}_i^{t-1} \frac{H_{i,t-1}}{H_{t-1}}\right)} = \frac{\sum_i \widehat{w}_i^{t-1} H_{i,t}}{\sum_i \widehat{w}_i^{t-1} H_{i,t-1}} \frac{H_{t-1}}{H_t} \tag{1}$$

where $H_{i,t}$ denotes the number of hours worked by all workers of type i at time t, H_t refers to the total number of hours worked in the economy at time t. As productivity-linked weights, the first subindex uses theoretical wages, for each worker type i, obtained from wage regression estimated on data from time $t-1$, denoted as $\widehat{w}_i^{t-1}$.

The second subindex uses theoretical wages from an estimation on data from time t, $\widehat{w}_i^t$:

$$dQ_t^1 = \frac{\sum_i \left(\widehat{w}_i^{t} \frac{H_{i,t}}{H_t}\right)}{\sum_i \left(\widehat{w}_i^{t} \frac{H_{i,t-1}}{H_{t-1}}\right)} = \frac{\sum_i \widehat{w}_i^{t} H_{i,t}}{\sum_i \widehat{w}_i^{t} H_{i,t-1}} \frac{H_{t-1}}{H_t} \tag{2}$$

A final indicator used by Aaronson and Sullivan (2001) follows a formula for Fisher's ideal index:

$$dQ_t = \left(dQ_t^0 \times dQ_t^1\right)^{0.5} \tag{3}$$

If the parameters in wage equations are stable over time or change little, the subindices are similar to each other and the formula for the growth rate of the quality of the labour input can be simplified by using the same theoretical wages based on pooled sample estimation results, $\widehat{w}_i$, for each subindex. Then, the growth rate of the quality of the labour input is simply:

$$dQ_t = \frac{\sum_i \widehat{w}_i H_{i,t}}{\sum_i \widehat{w}_i H_{i,t-1}} \frac{H_{t-1}}{H_t} \tag{4}$$

Note that the first element of the right-hand side of equation (4), $\frac{\sum_i \widehat{w}_i H_{i,t}}{\sum_i \widehat{w}_i H_{i,t-1}}$, represents the growth rate of the quality-adjusted labour input, whilst the second element is the growth rate of the unadjusted labour input (hours worked). Moreover, in the light of equation (4) the labour quality growth rate can be interpreted as growth in average theoretical wages in the economy (Aaronson and Sullivan, 2001). The cumulative change in labour quality over several years can be obtained as a chain-linked index using yearly indices.

3.2 Alternative measure of labour quality

The alternative approach for calculation of the quality of the labour input utilises the Törnqvist index formula. Firstly, the growth in the quality-adjusted total labour input, L_t, is represented as the weighted sum of growth rates of raw hours worked for each type of worker, where weights reflect the share of each group of workers in total compensation in two adjacent points:

$$dL_t = \ln\left(\frac{L_t}{L_{t-1}}\right) = 0.5 \sum_i \left(s_{i,t} + s_{i,t-1}\right) \ln\left(\frac{H_{i,t}}{H_{i,t-1}}\right) \quad \text{where} \quad s_{i,t} = \frac{\widehat{w}_i H_{i,t}}{\sum_i \widehat{w}_i H_{i,t}} \tag{5}$$

Then the growth in labour quality is calculated as a difference between the growth rate of the quality-adjusted labour input and growth rate of total hours worked (unadjusted labour input), i.e. $dH_t = \ln \frac{H_t}{H_{t-1}}$.

$$dQ_t = dL_t - dH_t = 0.5 \sum_i \left(s_{i,t} + s_{i,t-1}\right)\left(dH_{i,t} - dH_t\right) \tag{6}$$

This approach to calculate labour quality is apparently dominant in the literature and it was used in most of the studies mentioned in part 2 (Bell et al., 2005; Dey-Chowdhury and Goodridge, 2007; Kolasa and Strzelecki, 2007; Schwerdt and Turunen, 2007; Baldassarini and di Veroli, 2009; Bolli and Zurlinden, 2009; Keeney, 2010; Schwerdt and Turunen, 2010; Zoghi, 2010; Gradzewicz et al., 2018). However, since equations (5) and (6) use a log difference, there is a problem to apply this method when the number of hours worked by a certain group of workers falls to zero. In this case the group of workers is dropped from the calculations. Bosler et al. (2017) argue that dropping zero observations can be reasonable, as their share in total compensation is, most likely, negligible. However, when using survey data this problem might be relatively frequent if the number of defined groups of workers is large. The Aaronson-Sullivan formulation of the labour quality index does not suffer from the zero observations problem, hence it seems superior to the Törnqvist index formula when survey data are used and groups of workers are narrowly defined.

Taking all this into account, I use the simplified Aaronson-Sullivan formula, represented by equation (4), as my default method to calculate the change in the quality of the labour input. To check the robustness of the results, I investigate the simplified Aaronson-Sullivan formula with different sets of weights and I calculate the changes of the labour quality using the full Aaronson-Sullivan formula as in equations (1)-(3). Finally, I complement the results with calculations of the change of the labour quality using the Törnqvist index formula. However, as I demonstrate further, the results are close to each other. Also Bosler et al. (2017) note that when the zero observations problem is absent both approaches give virtually identical labour quality growth series.

3.3 Weights

The weights used for quality adjustment play a key role in the analysis. They should represent the productivity of different types of workers. The standard neoclassical assumption is that worker's productivity is reflected by his or her wages. Following this, the weights are obtained as theoretical wages from the wage equation (Aaronson and Sullivan, 2001). More precisely, I use a part of the predicted wages which corresponds to the worker's productivity-related characteristics, similarly to Zoghi (2010). For the purpose of this study, the key variables used to adjust for worker's productivity are: education, experience, gender and occupation.[5]

The wage equation (7) has the Mincerian-like form. The dependent variable is real net hourly wage, while the set of explanatory variables consists of education level (categorical variable, edu), experience (exp) and experience squared, gender (dummy variable for females, fem), occupation (categorical variable, occ) and additional control variables (X) including: part-time work (dummy variable), temporary work (dummy variable), region (categorical variable), degree of urbanisation (categorical variable) and year dummies (see Table 1 for the detailed description of variables).

$$\ln w_j = \alpha + \beta edu_j + \gamma_1 exp_j + \gamma_2 exp_j^2 + \delta fem_j + \zeta occ_j + \eta X_j + \varepsilon_j \tag{7}$$

$$\widehat{w}_j = \exp\left(\widehat{\beta} edu_j + \widehat{\gamma}_1 exp_j + \widehat{\gamma}_2 exp_j^2 + \widehat{\delta} fem_j + \widehat{\zeta} occ_j\right) \tag{8}$$

In the baseline approach, the wage equation is estimated using all the above-mentioned variables. Theoretical wages, $\widehat{w}_j$ are obtained using estimated coefficients for education, experience, gender and occupation only (equation 8). One can think about these four variables as reflecting worker-linked productivity,

[5] Occupation can be seen as classifying similar skill sets or human capital types (Zoghi, 2010).

whilst the rest of the variables control for other factors of wage determination. For robustness analysis, narrower specifications of wage models are also considered, i.e. I exclude additional controls and some key variables (cf. columns 1-3 in Table 3). For the full Aaronson-Sullivan approach the wage regression is estimated for each year separately whilst for other approaches the pooled sample is used.

3.4 Data

The study uses data from the Polish Labour Force Survey (*Badanie Aktywnosci Ekonomicznej Ludnosci*, BAEL). It is one of the Labour Force Surveys conducted in the EU by national statistical institutes and supervised by Eurostat. Eurostat ensures comparability of methodology of surveys across countries. The BAEL survey is representative and the most comprehensive survey of the workforce in Poland. It is widely used as a data source for labour analyses for Poland, including calculation of official labour market indicators (e.g. unemployment rate) reported by Eurostat. From the perspective of this study, the survey contains information on workers' characteristics, their wages and hours worked. However, the BAEL survey has some limitations that should be mentioned. Giving an answer to the question about a worker's wage is not compulsory and the worker can decline it. In fact, the share of workers who decline is substantial, with only 31% of workers revealing their wages. Nevertheless, the wage results from the BAEL survey are broadly in line with other data sources.[6] A further limitation of the BAEL survey is that it covers only a small portion of migrant workers in Poland, which gains importance in the face of a substantial inflow of migrants, especially from Ukraine, into Poland in the past several years.[7]

[6] The no response is probably not random, with high-earning workers being presumably more reluctant to reveal their wages. However, because I trim outlying wages otherwise, underrepresentation of higher earners is not a problem.

[7] Strzelecki et al. (2022) estimate that the number of Ukrainian immigrants working in Poland was between 0.9-1.1 million in 2018. They demonstrate that migrant workers from Ukraine contribute negatively to labour quality growth as they are overrepresented in low-skilled jobs.

To calculate the hourly wage, I take monthly net nominal wages reported by the respondents, deflate them using the CPI and divide by the number of hours worked usually by the worker. The outlying values of hourly wages are excluded from the sample by trimming one percent of the lowest and one percent of the highest values for each occupation-year group. To calculate the number of hours worked I use information on hours actually worked by workers in the surveyed week.

Education in the survey is reported as the highest attained education level. There are seven education levels: doctoral degree (ISCED 8), bachelor's or master's degree (ISCED 5-7), post-secondary non-tertiary education (*wyksztalcenie policealne*, ISCED 4), upper secondary, vocational (*wyksztalcenie srednie techniczne*, ISCED 3), upper secondary, general (*wyksztalcenie srednie ogolnoksztalcace*, ISCED 3), basic vocational (*wyksztalcenie zasadnicze zawodowe*, ISCED 3), lower secondary or primary education (*wyksztalcenie gimnazjalne lub nizsze*, ISCED 0-2). Experience is grouped into 5-year intervals based on respondents' precise answers on their total working experience, in present and previous workplaces summed up. Contrary to other studies, I do not use age as a proxy for experience, but instead I use a direct indicator of experience.[8] Occupations are grouped into ten categories according to ISCO classification.

With seven education levels, ten occupation categories, two genders and experience grouped into 5-year intervals I end up with 1,479 distinct categories of workers, which is by far a more detailed grouping than in other studies. For instance, Schwerdt and Turunen (2007) group workers according to three education levels, two genders and 10-year age intervals, which results in only 36 categories of workers. However, with a very large number of categories there is a risk of zero observations and hence the calculations of labour quality using the Törnqvist index might be flawed.

[8]Due to lack of information on experience, many other studies use worker's age as a proxy for experience. Although age and experience are strongly correlated, they do not follow each other perfectly, since the length of worker's employment spells is affected by education and gender, with high-skilled and male workers performing better in this regard. However, Schwerdt and Turunen (2010) demonstrate that using actual experience instead of age does not fundamentally change the results for the labour quality calculations.

4 Descriptives

The Polish labour force has been undergoing a significant compositional shift following a change in educational choices of young Poles and expansion of tertiary education.[9] To illustrate this shift, Table 2 presents the composition of hours worked in the Polish economy in 2006-2020 according to education, occupation and gender. The improvement in educational structure was the most pronounced change, with better educated workers substantially increasing their share in total labour input. In 2006-2020 the share of hours worked by individuals with bachelor's or master's degree grew dramatically from 20.0% to 34.9%. At the same time, shares of hours worked by individuals with lower secondary and primary education as well as basic vocational education fell from 9.0% to 4.6% and from 32.0% to 23.8%, respectively.

The improvement in educational structure was followed by changing occupational structure. Professionals and technicians and associate professionals expanded their shares in total hours worked by 6.8 p.p. and 2.5 p.p., whilst a sizeable reduction affected skilled agricultural, forestry and fishery workers (change -4.5 p.p.), elementary occupations (-2.1 p.p.), craft and related trades workers (-1.2 p.p.). Such a shift in the structure of occupations means that the expansion of tertiary education coincided with increasing demand for jobs requiring more educated workers. However, as tertiary education expansion was far stronger than growth of jobs which require tertiary education – managers, professionals, technicians and associate professionals increased their share in total hours worked by almost 9 p.p. – it suggests rising underutilisation of tertiary education, so-called overeducation.

The gender composition of hours worked showed no significant change in 2006-2020, with only minor fluctuations. The average share of hours worked by men in 2006-2020 was 59.0%, with minimum shares of 58.7% in 2009 and 2018, and maximum ones of 59.2% in 2006 and 2020.

[9] The gross enrolment ratio for tertiary education rose from 13% in 1990 to 52% in 2020.

Moreover, the working population got on average more experienced in 2006-2020 (see Table 2). In the year 2006, the average experience, weighted with hours worked, was 18.1 years (18.6 for males and 17.3 for females). By 2020 it rose by one and a half year to 19.6 years in the general population (to 20.2 years for males and 18.6 years for females). A more experienced workforce means a greater stock of human capital, ceteris paribus.[10]

Taking all this into account, three compositional changes, referring to education, occupation and experience, supported labour quality growth in Poland. Gender composition, due to exactly the same shares at the beginning and the end of the period, was neutral for the labour quality growth.

[10]Experience exerts a non-linear effect on worker's productivity and wages. The results of wage regression estimations (Table 3), in which experience is introduced with its squared term, imply the highest wages for workers of between 29 years of experience (model 4 in Table 3) and 35 years of experience (model 1).

5 Wage regression

Table 3 summarises the results of the estimation of the wage equation. It presents the results for four model specifications. The broadest model specification (column 4) serves as the baseline, whilst the more parsimonious models 1-3 can be treated as robustness checks. Estimation results for each year separately are presented in Table 4. The results of different specifications are qualitatively similar to each other.

Education attainment significantly differentiates hourly wages. According to the baseline model, a doctoral degree increases the hourly wage by 18% compared to the reference level, which is bachelor's or master's degree. Post-secondary non-tertiary education, vocational upper secondary education and general upper secondary education decrease hourly wages by 15-17% compared to the reference level. Workers with basic vocational education experience wages 23% lower than the reference level and 29% lower than workers with lower secondary or primary education. However, more parsimonious models would imply much larger wage differentials. For instance, according to model 1, including only education and experience, workers with a doctoral degree get 34% higher hourly pay than workers with bachelor's or master's degree, whilst workers with post-secondary non-tertiary education, vocational upper secondary education and general upper secondary get around 34-35% lower pay. According to the same model, hourly wages of workers with basic vocational education as well as workers with lower secondary or primary education are lower than wages of workers with bachelor or master degree by 44% and 51%, respectively.

Estimation results for experience show the inverted U-shaped relationship with hourly wage. Workers at the beginning of their work careers experience the highest wage growth with an additional year of experience. The wage growth slows down with gaining experience. For the baseline model (model 4), wages reach their highest values for workers with 25-29 years of work experience, all else equal. For more parsimonious models, the highest wages occur for slightly older workers, e.g. model 1 implies the maximum wage for 30-35 years of work experience.

Furthermore, the results show that women experience lower hourly wages, by about 15%-19%, compared to men. Occupation also significantly differentiates wages. Managers and armed forces earn the highest hourly wages, 10% and 12% higher than professionals according to the baseline model. Service and sales workers, skilled agricultural, forestry and fishery workers and elementary occupations earn the lowest hourly wages, around 35% lower than professionals.

Additional controls, except working part-time, add to explaining wage differentials between workers. Temporary contracts are associated with hourly wages 12% lower compared to permanent contracts. Spatial differences play a role as well: workers in Mazowieckie voivodship earn the highest wages, whilst the lowest hourly wages are earned by workers in Swietokrzyskie and Podkarpackie voivodships. There is also a positive relationship between the degree of urbanisation and the level of hourly wages, with workers in rural areas earning 8% less compared to workers in cities with at least 100 thousand inhabitants.

Table 4 summarises the results of wage regressions estimated for each year separately. The results clearly show a falling wage premium on tertiary education. For instance, workers with vocational upper secondary education were paid 25% less compared to tertiary educated workers in 2006, whilst in 2020 it was only 12% less. Similarly, workers with basic vocational education were paid 31% less compared to workers with bachelor's or master's degree in 2006, and 18% less in 2020. Such a tendency of falling wage differentials compared to tertiary education is observed for all lower education levels. Moreover, it is supported by a similar picture emerging from coefficients for occupation. Wage differentials between high-skilled occupations and low-skilled occupations decreased in 2006-2020. For instance, in 2006 plant and machine operators and assemblers earned 23% less compared to professionals (the reference group in the estimation), but the difference decreased to 17% in 2020. A decreasing wage premium associated with high skills turns out to have important implications for the labour quality index. When calculating the labour quality index according to the full Aaronson-Sullivan formula, using parameters from wage equations estimated independently for each year, a falling skill premium will result in more profound changes in the labour quality index at the beginning of the analysis and more suppressed at the end, all else equal.

6 Labour quality

6.1 Growth of unadjusted labour input (hours worked)

In 2006-2020, the average growth rate of the total number of hours worked in the economy was close to zero (0.1% a year). It was a result of a substantial improvement in the number of people in employment, which rose on average by 0.8% a year, and decreasing intensity of work, which was reflected by the falling average number of hours per worker, by 0.7% a year. When the pandemic-affected year 2020 is excluded, the average growth rate of the total number of hours worked goes up to 0.4% a year, which was driven by 0.9% of employment growth rate and -0.5% of growth rate of average number of hours per worker. Except for 2020, the average number of hours per worker fluctuated much less compared to the number of workers, which means that the total labour input adjusted relatively more via an extensive margin (number of workers) rather than an intensive margin. Contrary to previous periods, the reaction to the pandemic in 2020 was mainly via an intensive margin. A small decrease in headcount employment (-0.1%) was combined with a substantial decrease in the average number of hours per worker (-3.6%).

6.2 Labour quality and quality-adjusted labour input

Labour quality substantially improved over 2006-2020. According to the baseline approach, which uses the simplified Aaronson-Sullivan index and full model estimation results, the average labour quality growth in Poland was 0.55% a year in 2006-2020. However, the growth rate of labour quality fluctuated over the analysed period, showing a negative relationship with hours worked (Figure 2). In the two first years, the labour quality growth was close to zero, but at the same time there was a high growth rate of the total number of hours worked (see Figure 2). Then, it was followed by two years, 2009-2010, affected by the global financial crisis, when substantial contraction in total number of hours worked (on average -2.0% a year) coincided with a strong improvement in labour quality (average of 1.1% a year). The year 2011 was the only year when labour quality decreased, although slightly, by 0.2%, with some improvement in hours worked. The years 2012-2013 again showed a substantial improvement in labour quality combined with negative changes in the number of hours worked. The following years until the end of the analysis experienced moderately positive changes in labour quality with some temporary slowdown around 2015. In 2020, due to the COVID-19 pandemic, the number of hours worked decreased substantially by 3.7%, but it was partially offset by an improvement in labour quality. In 2006-2020, the labour quality improved by 8.0% in total.

As the quality-adjusted labour input is a product of the unadjusted labour input (hours worked) and labour quality, the quality-adjusted labour input grew by 0.66% a year (0.55 p.p. from labour quality and 0.11 p.p. from hours worked). In 2006-2020, the total growth of the quality-adjusted labour input equalled 9.3% (and 12.8% in 2006-2019). This is much higher value than the growth rate of the unadjusted labour input (1.3% for 2006-2020, and 5.2% for 2006-2019). Hence, it illustrates that focusing solely on changes in hours worked substantially underestimates the importance of changes of the labour input.

Furthermore, changes in labour quality are counter-cyclical. The change in labour quality is negatively correlated with both the real GDP growth rate (correlation coefficient -0.45, see Table 7) as well as changes in the number of hours worked (correlation coefficient -0.67).[11] It means that during periods of strong economic expansion, more low-skilled workers enter employment. As a result, the expansion of employment is usually associated with deceleration of labour quality growth. On the other hand, during unfavourable labour market conditions, when employment falls, the employment reduction is relatively stronger for low-skilled workers. As a result, the labour quality improves in periods of falling utilisation of the labour input. Hence, adjustments in labour quality partially cushion fluctuations of the unadjusted labour input.

[11]When the year 2020 is excluded, negative correlations get stronger. The correlation of labour quality and the GDP growth rate is -0.57, whilst the correlation of labour quality and change in hours worked is -0.73.

Moreover, detailed quarterly data (not reported in the paper) show that labour quality fluctuates seasonally. It is associated with seasonality of work in such sectors as agriculture and construction, which require low skill levels. As a consequence, the average labour quality is about 2% lower in summer than in winter.

6.3 Gender, regional and sectoral variation in labour quality

Let us now investigate gender, regional and sectoral differences in labour quality. When calculated separately for women and men, the labour quality grew faster for women. The difference is substantial as average labour quality growth for men was 0.45% a year compared to 0.72% for women (Figure 3). In total, in 2006-2020 the labour quality grew by 6.4% for males and 10.5% for females. As a result, women's contribution to the total change in labour quality was 4.3 p.p. compared to 3.8 p.p. for men. Faster labour quality growth for women resulted from an improvement in educational composition stronger for women than men.

There is significant regional variation in labour quality, both in levels[12] and changes. The highest values of labour quality are found in Mazowieckie and Dolnoslaskie voivodships, where the labour quality index in 2020 was higher than the country average by 5.5% and 4.0%, respectively (see Figure 4). Above-average values of the labour quality index in 2020 were found also in Pomorskie, Malopolskie and Slaskie. The lowest levels of labour quality were observed in relatively rural regions: Warminsko-Mazurskie, Swietokrzyskie and Podlaskie, in which labour quality was around 4% lower than the country average. It suggests that the most productive workers are concentrated in urbanised regions. Moreover, all regions experienced an improvement in labour quality in 2006-2020, with Lubelskie having the strongest improvement (by 11% in total), and Zachodniopomorskie and Warminsko-Mazurskie having weakest ones (4%).

[12] Comparisons of *levels* of labour quality between groups means de facto a comparison of average theoretical wages.

There is also large sectoral variation in values of the labour quality index due to different educational, gender and occupational composition of the workforce within sectors (Figure 5). The highest value of the labour quality index is observed in sector J *Information and communication* (the labour quality index was 32% higher than the country average in 2020), followed by sectors: M *Professional, scientific and technical activities* (24% higher than the average), K *Financial and insurance activities* (23% higher than the average), O *Public administration, defence* (19% higher than the average), P *Education* (18% higher than the average). The lowest values of the labour quality index are found in sector A *Agriculture, forestry and fishing* (22% lower than the average) and sector I *Accommodation and food service activities* (19% lower than the average). Referring to the changes in labour quality, sectors K *Financial and insurance activities* and L *Real estate activities* experienced the strongest growth in the labour quality index (indices for both sectors grew by 11% in 2008-2020), whilst S *Other service activities* (decrease of 2%) and F *Construction* (growth of 3%) experienced the weakest improvements.[13]

6.4 Decomposition of labour quality growth

Table 6 and Figure 6 present the results of decomposition of changes of the labour quality index. The shift in educational structure was the main driver of the improvement in labour quality, contributing 0.30 p.p. out of 0.55% of average annual increase of labour quality in 2006-2020. The second largest contribution to labour quality improvement was due to the shift in occupational structure, which contributed 0.21 p.p. a year on average. Two other components of labour quality played minor roles. The change in experience also positively contributed to labour quality, however adding only 0.03 p.p. a year. The average contribution of gender was zero, and it was due to the same gender shares in the structure of hours worked in 2006 and 2020.

[13]Because of the revision of NACE classification which entered into force in 2008, changes in labour quality for sectors are reported for 2008-2020.

All components of labour quality show negative correlation with GDP growth and growth of total number of hours worked. It means that during periods of economic expansion people with characteristics related to lower labour quality increase their shares in total hours worked. In other words, high labour demand causes employers to hire individuals having lower-quality characteristics who would be rejected otherwise, as well as high wage growth in that time makes individuals with weak labour market attachment and lower productivity enter the labour force or stay longer in employment.

6.5 Robustness of results

To check the validity of results, I confront the results of the baseline approach, i.e. the simplified Aaronson-Sullivan approach using coefficients from the broadest wage model, with results obtained with other methods. In general, the results are qualitatively similar to each other (see Figure 7), which supports the general view from the baseline results, however some noteworthy differences are present.

The results of the baseline approach are almost identical to the results of the Törnqvist index. The average change of labour quality calculated using the Törnqvist index was 0.54% a year. It is because both the baseline approach and the Törnqvist index use the same productivity weights, although they use different index formulas. Although the Törnqvist index might potentially suffer from the zero observations problem, its results are still very close to the simplified Aaronson-Sullivan index and the problem seems negligible.

Compared to the simplified one, the full Aaronson-Sullivan index clearly shows larger growth rates of labour quality at the beginning of the analysed period and smaller growth rates at the end of the period. It results from the changing productivity weights when the wage equation is estimated for each year separately. Specifically, as reported in part 5.1, yearly wage estimations show that high skill premia decreased with time. As a result, positive educational change adds more to labour quality improvement at the beginning of the period than at the end of the period. Nevertheless, the average change in labour quality based on the full Aaronson-Sullivan was 0.53% a year, only slightly less than the average change reported by the simplified Aaronson-Sullivan index.

Furthermore, I investigate the effects of a different specification of the wage model. Models 1-3 (Table 3) include a shorter list of explanatory variables than the baseline model 4. They also lead to much greater improvements in labour quality than the baseline. When using the results of the most parsimonious wage model, having only education and experience as explanatory variables, the average labour quality growth was 0.78% a year, substantially more than baseline results. The addition of gender to explanatory variables, as in model 2, results in even slightly stronger labour quality improvements (on average 0.82% a year). Adding occupation to a wage model, but without other controls (model 3), reduces average labour quality growth to 0.70% a year, though it is still above the baseline results. Moreover, when productivity weights are driven from either model 1 or 2, there is no decline in labour quality in a single period, contrary to the model 3 and the baseline model 4, which show a decrease in labour quality in 2011. Hence, it seems that adding more controls to a wage equation tends to reduce labour quality growth. This finding has important implications as many other studies quantifying labour quality use rather smaller sets of explanatory variables in wage equations, and hence these studies probably overestimate the true growth in labour quality.

7 Conclusion and discussion

The paper examines the evolution of labour quality in Poland in 2006-2020. It is recognised in the literature that the total number of hours worked in the economy is a limited measure of the labour input as it implicitly assumes that all workers are equally productive. Hence, a more accurate measure of the labour input should be productivity-adjusted to account for differences in characteristics between workers. The labour quality is a synthetic measure of changes in the composition of workers' characteristics, proxying for growth in human capital endowment. It is obtained by comparing the quality-adjusted labour input and unadjusted labour input. Whilst the latter consists of an unweighted sum of hours worked in the economy, the former is a weighted sum of hours worked in the economy where weights reflect workers' productivity. For this study, weights are calculated using coefficients for education, experience, gender and occupation estimated in a wage regression. Data from the Polish Labour Force Survey are used. Unlike other studies, this paper uses very narrowly defined groups of workers – with seven education levels, two genders, ten occupation categories and experience reported in 5-year intervals there are almost 1,500 worker categories. Moreover, a direct measure of experience is used instead of proxying it with age as many other studies do.

The results show a substantial improvement in the quality of the labour input in Poland in 2006-2020, meaning that workers with characteristics linked to higher productivity increased their share in the total number of hours worked in the Polish economy. According to the baseline results, using the simplified Aaronson-Sullivan index, labour quality grew on average by 0.55% a year. Labour quality growth was positive in all but one period. Moreover, the results show that labour quality for females rose in Poland much faster than labour quality of men (0.72% a year for females compared to 0.45% a year for men). The improvement in the educational structure is found to be the main driver behind the labour quality changes. Improving educational structure contributed on average 0.30 p.p. out of 0.55% of labour quality growth, the change in occupational structure contributed 0.21 p.p., whilst experience and gender had negligeable contributions.

Labour quality growth shows less volatility compared to growth of hours worked in the economy (unadjusted labour input). Moreover, it is negatively correlated with both growth in hours worked and GDP growth. A a result, labour quality mitigates the procyclicality of the labour input. In 2006-2020, the total growth of the quality-adjusted labour input equalled 9.3%, of which 8.0 p.p. can be attributed to an improvement in labour quality, whilst the rest (1.3 p.p.) was due to the change in hours worked. Hence, focusing solely on changes in hours worked substantially underestimates the importance of changes of the labour input. To illustrate this with simple algebra, with the labour share equal to 0.54 (value taken from EUKLEMS), the average contribution of the raw labour input to output growth in 2006-2020 was 0.06 p.p. a year, whilst the contribution of quality-adjusted labour growth was 0.35 p.p.

Alternative labour quality indices show a generally similar picture of substantial improvement of labour quality, but some important differences can be reported. When productivity weights are calculated for each year separately, as in the full Aaronson-Sullivan formula, labour quality growth rates are higher at the beginning of the analysed period and lower at the end compared to the baseline results using time-constant weights. However, the full Aaronson-Sullivan formula gives virtually the same average change in labour quality as the baseline. The labour quality growth path based on Törnqvist index is almost identical to the simplified Aaronson-Sullivan index. Furthermore, more limited sets of explanatory variables tend to result in higher average changes in labour quality.

The finding that education is a dominant driver behind changes in labour quality, being in line with the findings for other countries, has important implications for the future quality-adjusted labour input. With deceleration of educational change, as tertiary education enrolment rates stabilise at new high levels, one can expect a slowing down of labour quality growth. A similar prediction is made for the US by Bosler et al. (2017).

Although the estimation of the augmented Mincerian wage equation is the intermediate step in the calculation of labour quality, it provides an interesting finding about the evolution of the education wage premia in Poland. The results for wage equations estimated for each year separately show that wage differentials between tertiary educated workers and workers with lower education levels substantially decreased in 2006-2020. For instance, workers with vocational upper secondary education were paid 25% less compared to tertiary educated workers in 2006, whilst in 2020 it was only 12% less. This agrees with the findings of Wincenciak (2020), who reports that returns to schooling in Poland followed the inverted U-shaped path in 1995-2017 and started decreasing in 2006. A likely driver of falling teriary education wage premia is the substantial expansion of tertiary education in the workforce, with the share in hours worked rising from 20.0% in 2006 to 34.9% in 2020, which probably outpaced demand for tertiary-educated workers. However a more comprehensive analysis is needed to verify this suggestion.

As an agenda for future research, a more accurate measure of labour quality could be potentially obtained with productivity weights covering further workers' productivity-related characteristics. For instance, when calculating productivity weights, there could be included more detailed information on workers' formal education, going beyond levels of education, such as quality of received formal education and field of studies. Ideally, a measure of workers' skills should be included as well, since many skills are acquired unrelatedly to formal education. With the growing role of the ICT sector, the need to account for computer literacy seems particularly important. Furthermore, indicators of worker's health might also be considered, as poor health and illness negatively affect a worker's performance. Bosler et al. (2017) mention such additional characteristics as entrepreneurial talent or even physical attractiveness. However, population-wide information on all these additional characteristics is scarce and fragmented, which limits broadening the scope of variables for productivity adjustment until new richer data sources are available.

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Figure 1: Change in hours worked (y/y, %)

Figure 2: Growth of labour quality index (y/y, %)

Figure 3: Growth of labour quality index, gender breakdown (y/y, %)

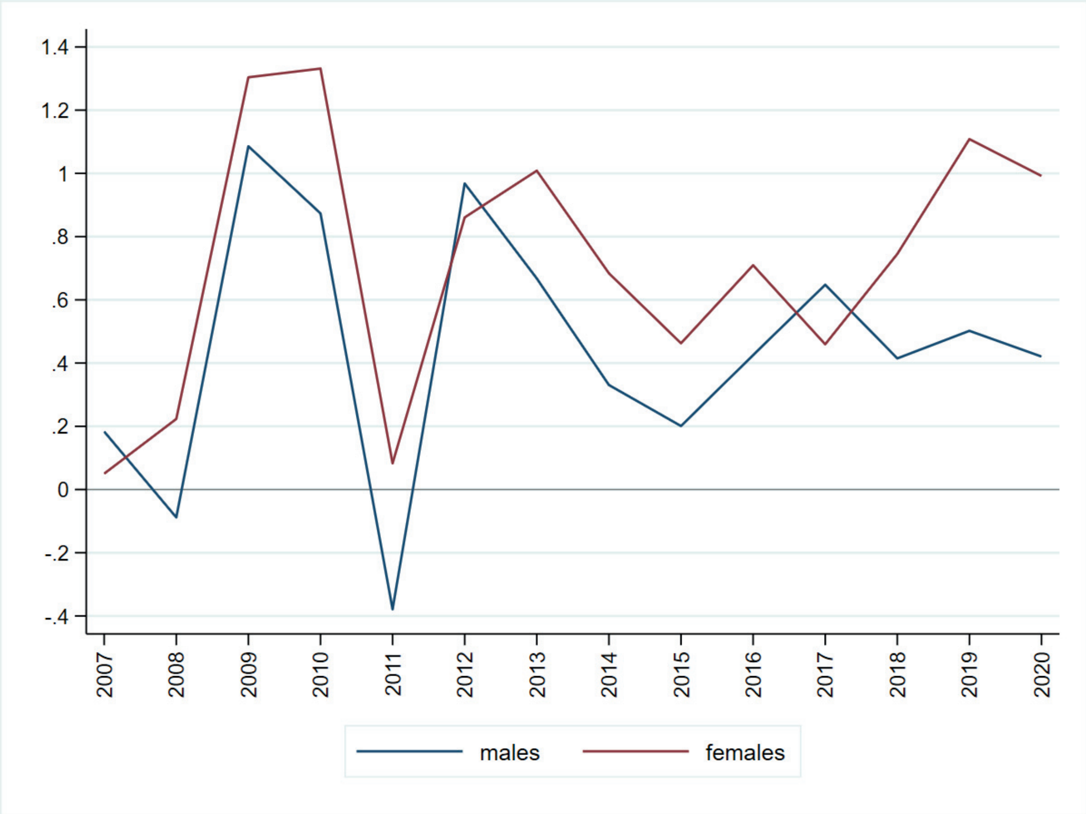

Figure 4: Deviation of labour quality index from country mean, regions, 2020 (%).

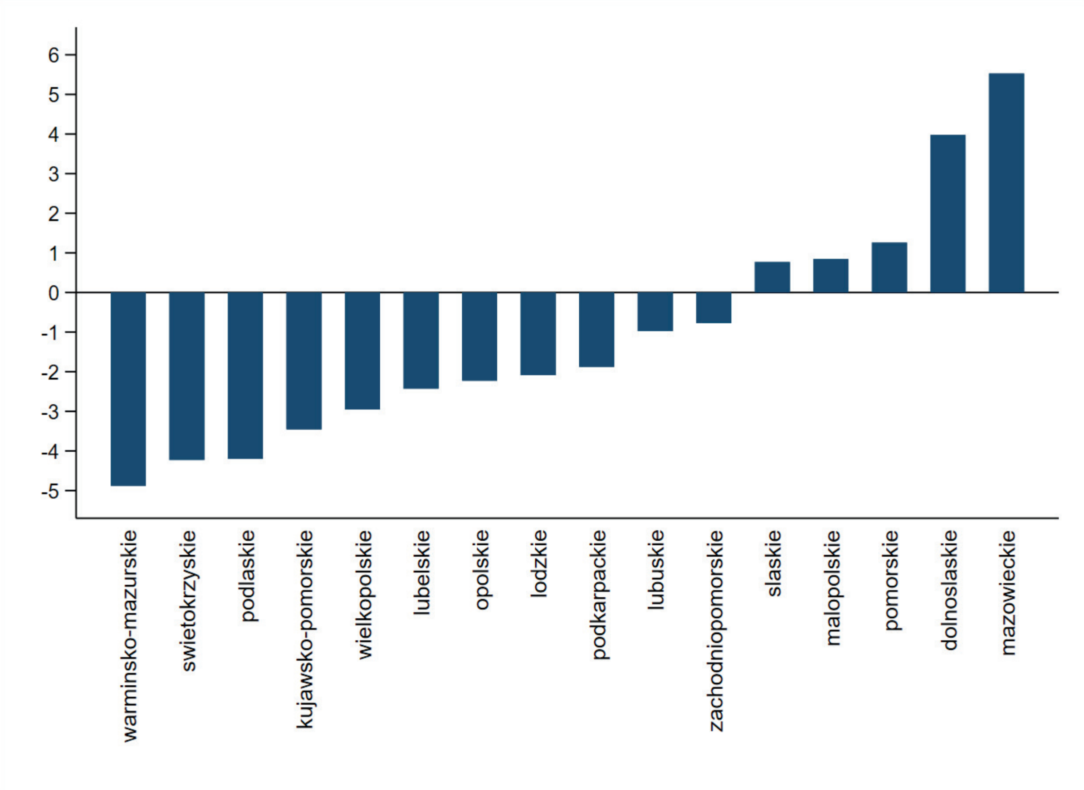

Figure 5: Deviation of labour quality index from country mean, sectors, 2020 (%)

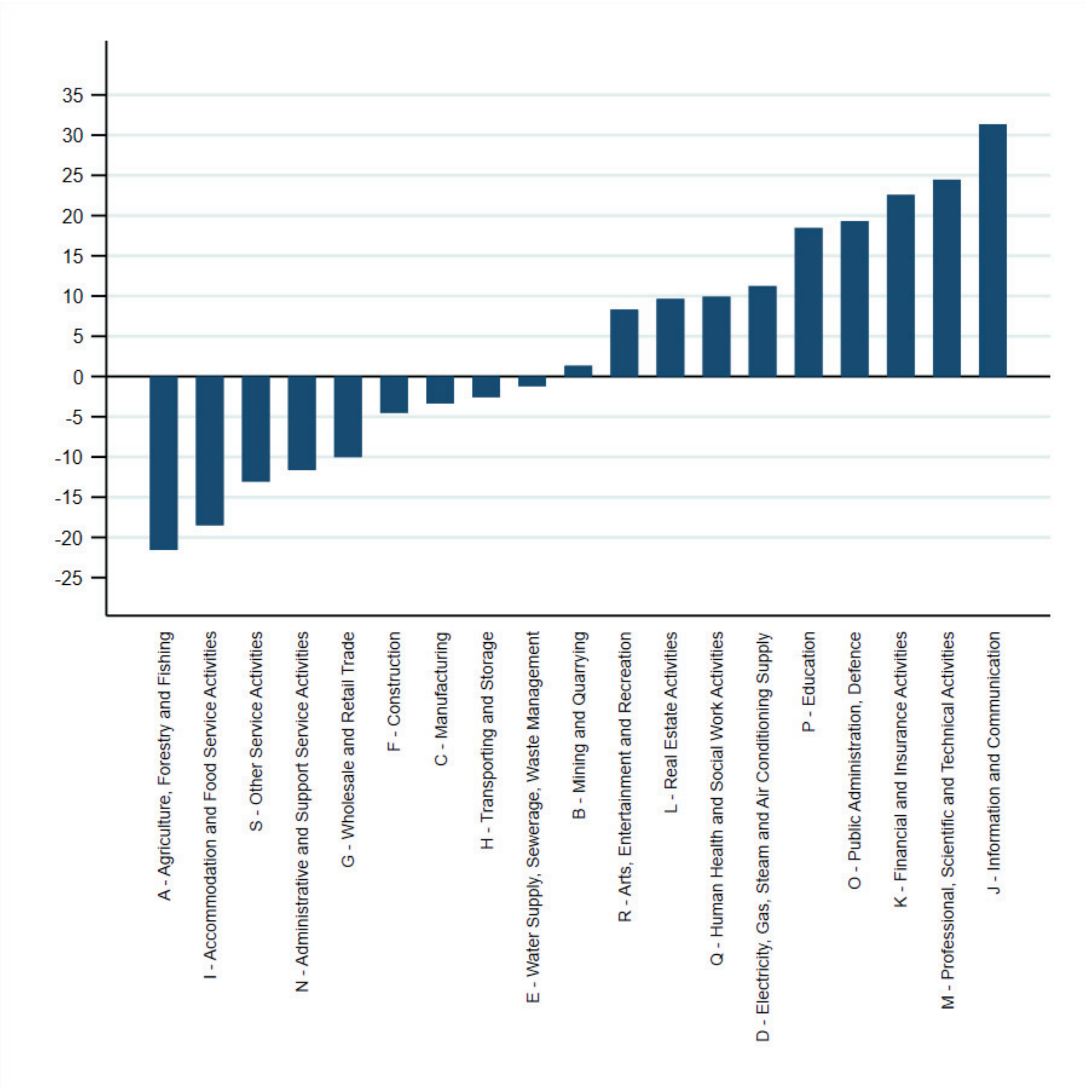

Figure 6: Decomposition of growth of labour quality index (y/y, %)

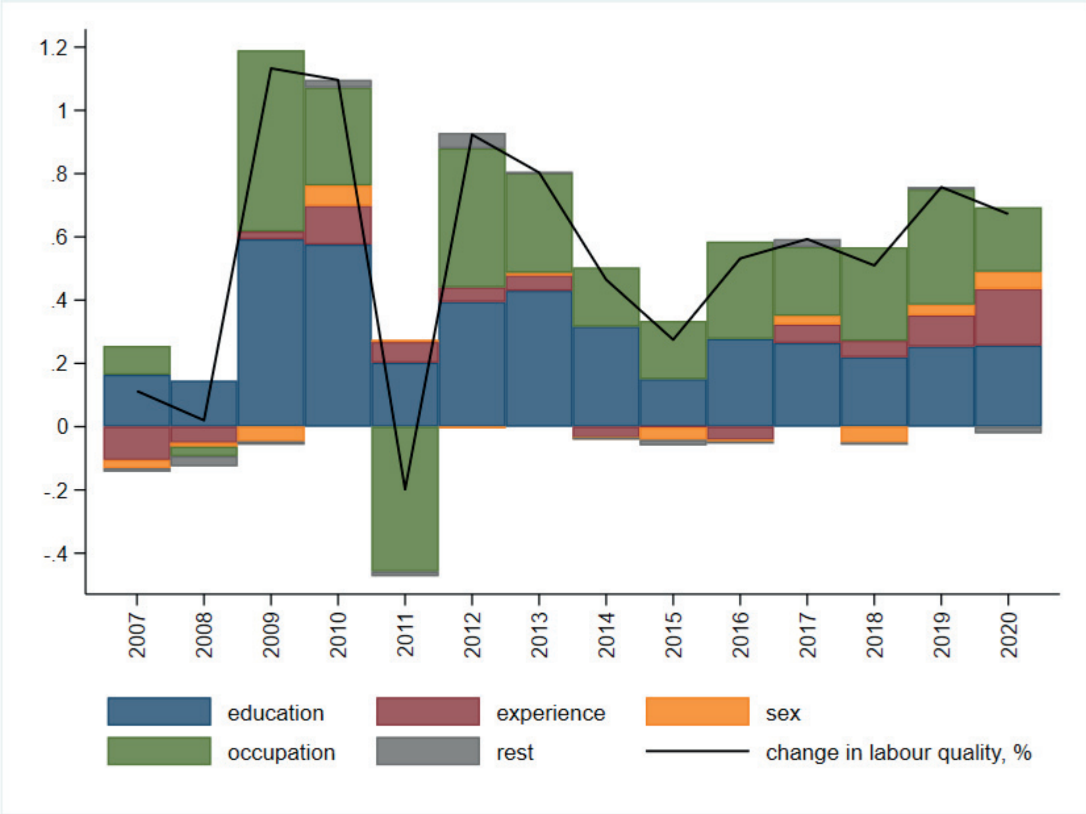

Figure 7: Growth of labour quality index, alternative approaches (y/y, %)

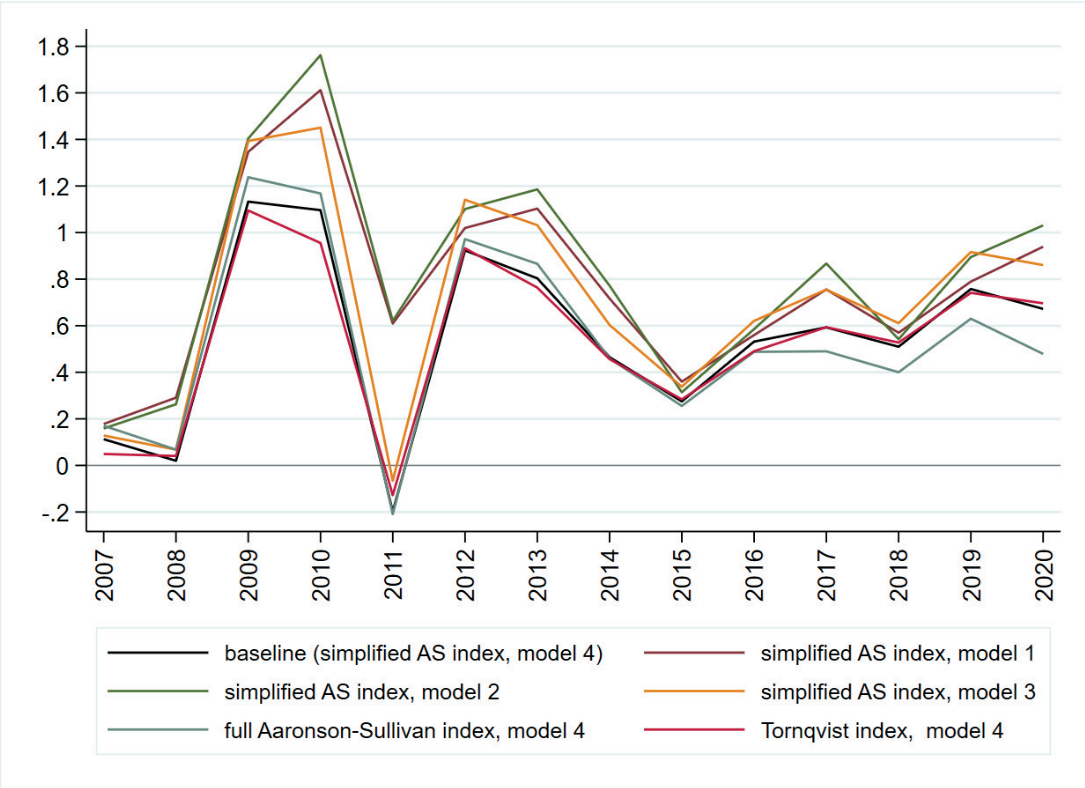

Table 1: Variable description

Variable	Description
hourly wage	Workers' real net hourly wages calculated as monthly nominal net wages deflated using CPI and divided by the number of usual hours of work in a workers' main job. One percent of lowest and one percent of highest values for each occupation-year combination are excluded from the sample.
education	Workers' highest completed education level, grouped into 7 categories: doctoral degree, bachelor's or master's degree (reference level), post-secondary non-tertiary education, vocational upper secondary, general upper secondary, basic vocational, lower secondary or primary education.
experience	Workers' total work experience (sum of the number of years worked in a current job and previous ones), grouped into 5-year intervals: 0-4, 5-9, 10-14, etc. Central value of the interval (2, 7, 12, etc.) is assigned to each interval.
female	Dummy variable taking value 1 for females, and 0 otherwise.
occupation	Workers' occupation in their main job reported as one of 10 major groups of International Standard Classification of Occupations. Professionals are the reference level.
part-time employment	Dummy variable taking value 1 for workers working part-time in their main job, and 0 otherwise.
temporary employment	Dummy variable taking value 1 for workers with temporary employment in their main job, and 0 otherwise.
degree of urbanisation	Size of workers' place of residence, grouped into 4 categories: towns with more than 100k inhabitants (reference level), towns with 20k-100k inhabitants, towns with less than 20k inhabitants, rural areas.
region	Voivodship of workers' place of residence. 16 voivodships.

Table 2: Structure of hours worked and average experience in working population, 2006-2020

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2006-2020 change, p.p.
Doctoral degree (ISCED 8)	0.4%	0.5%	0.5%	0.5%	0.6%	0.6%	0.6%	0.6%	0.7%	0.6%	0.7%	0.7%	0.7%	0.8%	0.8%	0.4
Bachelor's or master's degree (ISCED 5-7)	20.0%	20.5%	21.1%	23.2%	24.8%	25.7%	27.1%	28.6%	29.9%	30.5%	31.3%	32.2%	33.0%	33.9%	34.9%	14.9
Post-secondary non-tertiary education (ISCED 4)	3.9%	3.8%	3.8%	3.9%	3.6%	3.6%	3.6%	3.4%	3.4%	3.3%	3.2%	3.3%	3.1%	2.9%	2.9%	-1.0
Upper secondary, vocational (ISCED 3)	26.7%	26.5%	25.5%	24.9%	25.4%	25.3%	25.0%	25.0%	24.1%	24.3%	24.8%	24.3%	24.2%	24.1%	24.3%	-2.4
Upper secondary, general (ISCED 3)	7.9%	8.2%	8.4%	8.8%	8.7%	8.5%	8.6%	8.7%	8.8%	8.6%	8.4%	8.7%	9.0%	9.1%	8.8%	0.8
Basic vocational (ISCED 3)	32.0%	31.6%	32.0%	31.0%	29.6%	29.4%	28.6%	27.6%	27.3%	26.9%	26.3%	25.8%	25.2%	24.2%	23.8%	-8.2
Lower secondary or primary education (ISCED 0-2)	9.0%	8.9%	8.6%	7.8%	7.2%	6.9%	6.6%	6.1%	5.9%	5.8%	5.2%	4.9%	4.8%	4.9%	4.6%	-4.4
Managers (ISCO 1)	7.2%	7.2%	7.0%	7.3%	7.4%	6.6%	6.7%	6.8%	6.7%	6.5%	6.8%	6.7%	6.5%	6.6%	6.5%	-0.7
Professionals (ISCO 2)	13.1%	13.2%	13.1%	14.1%	14.8%	15.3%	16.3%	16.7%	17.2%	17.5%	17.6%	18.0%	18.7%	19.5%	19.9%	6.8
Technicians and associate professionals (ISCO 3)	10.9%	11.1%	11.3%	11.4%	11.6%	10.9%	10.7%	11.1%	11.6%	12.3%	12.7%	13.0%	13.3%	13.1%	13.4%	2.5
Clerical support workers (ISCO 4)	7.0%	7.1%	6.8%	6.9%	6.9%	6.5%	6.5%	6.5%	6.2%	6.0%	5.9%	6.0%	6.0%	6.0%	6.3%	-0.7
Service and sales workers (ISCO 5)	11.8%	12.0%	11.9%	11.8%	12.2%	14.4%	14.0%	13.9%	13.9%	13.3%	13.4%	13.1%	12.9%	12.6%	11.8%	0.0
Skilled agricultural, forestry and fishery workers (ISCO 6)	13.9%	12.8%	12.4%	12.0%	11.5%	11.4%	11.3%	10.9%	10.6%	10.9%	9.9%	9.4%	9.0%	8.7%	9.4%	-4.5
Craft and related trades workers (ISCO 7)	17.2%	17.5%	18.1%	17.7%	16.9%	16.6%	16.0%	15.8%	15.8%	15.8%	16.2%	16.1%	16.2%	16.5%	16.0%	-1.2
Plant and machine operators, and assemblers (ISCO 8)	11.1%	11.2%	11.4%	10.9%	10.9%	11.1%	11.1%	11.1%	10.8%	10.7%	11.0%	11.1%	11.0%	10.9%	10.8%	-0.3
Elementary occupations (ISCO 9)	7.3%	7.3%	7.4%	7.3%	7.3%	6.7%	6.7%	6.6%	6.6%	6.4%	6.1%	6.1%	5.8%	5.5%	5.1%	-2.1
Armed forces occupations (ISCO 0)	0.5%	0.4%	0.4%	0.6%	0.6%	0.5%	0.6%	0.6%	0.6%	0.7%	0.7%	0.6%	0.7%	0.7%	0.7%	0.2
Males	59.2%	59.0%	59.0%	58.7%	59.1%	59.1%	59.1%	59.1%	59.1%	58.9%	58.8%	59.0%	58.7%	58.9%	59.2%	0.0
Females	40.8%	41.0%	41.0%	41.3%	40.9%	40.9%	40.9%	40.9%	40.9%	41.1%	41.2%	41.0%	41.3%	41.1%	40.8%	0.0
Average experience (in years)	18.1	18.0	18.1	18.2	18.5	18.8	18.9	19.1	19.1	19.1	19.0	19.1	19.1	19.2	19.6	1.5
Males	18.6	18.7	18.8	18.9	19.1	19.3	19.4	19.7	19.6	19.6	19.5	19.7	19.7	19.9	20.2	1.6
Females	17.3	17.1	17.1	17.3	17.7	18.1	18.2	18.3	18.4	18.3	18.2	18.3	18.2	18.4	18.6	1.3

Table 3: Estimation results of wage equation

	I	II	III	IV
Education, ref.: Bachelor's or master's degree (ISCED 5-7)				
Doctoral degree (ISCED 8)	0.295***	0.261***	0.195***	0.168***
Post-secondary non-tertiary education (ISCED 4)	-0.431***	-0.411***	-0.265***	-0.184***
Upper secondary, vocational (ISCED 3)	-0.420***	-0.457***	-0.251***	-0.175***
Upper secondary, general (ISCED 3)	-0.419***	-0.430***	-0.215***	-0.163***
Basic vocational (ISCED 3)	-0.579***	-0.643***	-0.360***	-0.258***
Lower secondary or primary education (ISCED 0-2)	-0.707***	-0.762***	-0.459***	-0.339***
Experience	0.0214***	0.0230***	0.0182***	0.0138***
Experience squared	-0.00031***	-0.00035***	-0.00028***	-0.00024***
Female		-0.209***	-0.176***	-0.167***
Occupation, ref.: Professionals (ISCO 2)				
Managers (ISCO 1)			0.0953***	0.0928***
Technicians and associate professionals (ISCO 3)			-0.169***	-0.178***
Clerical support workers (ISCO 4)			-0.327***	-0.318***
Service and sales workers (ISCO 5)			-0.429***	-0.436***
Skilled agricultural, forestry and fishery workers (ISCO 6)			-0.418***	-0.412***
Craft and related trades workers (ISCO 7)			-0.317***	-0.306***
Plant and machine operators, and assemblers (ISCO 8)			-0.269***	-0.266***
Elementary occupations (ISCO 9)			-0.453***	-0.435***
Armed forces occupations (ISCO 0)			0.135***	0.112***
Part-time employment				0.00335
Temporary employment				-0.128***
Urbanisation, ref.: Cities with more than 100k inhabitants				
Cities with 20k - 100k inhabitants				-0.0561***
Cities with less than 20k inhabitants				-0.0777***
Rural areas				-0.0827***
Region dummies				YES
Year dummies				YES
Constant	2.473***	2.594***	2.701***	2.541***
Observations	75,408	75,408	75,408	75,408
R-squared	0.279	0.323	0.392	0.537

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 4: Parameters from wage equations estimated for each year separately

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Education, ref.: Bachelor's or master's degree															
Doctoral degree	0.239***	0.218***	0.0922	0.161**	0.170**	0.246***	0.212***	0.154*	0.175***	0.146***	0.153***	0.173***	0.155***	0.146***	0.167***
Post-secondary non-tertiary education	-0.289***	-0.265***	-0.214***	-0.193***	-0.202***	-0.171***	-0.183***	-0.223***	-0.168***	-0.174***	-0.165***	-0.152***	-0.135***	-0.119***	-0.135***
Upper secondary, vocational	-0.289***	-0.255***	-0.221***	-0.205***	-0.189***	-0.165***	-0.183***	-0.187***	-0.150***	-0.152***	-0.150***	-0.136***	-0.131***	-0.116***	-0.125***
Upper secondary, general	-0.255***	-0.234***	-0.202***	-0.176***	-0.183***	-0.161***	-0.176***	-0.176***	-0.144***	-0.147***	-0.155***	-0.137***	-0.110***	-0.117***	-0.141***
Basic vocational	-0.378***	-0.339***	-0.306***	-0.284***	-0.269***	-0.244***	-0.266***	-0.275***	-0.221***	-0.228***	-0.240***	-0.211***	-0.192***	-0.198***	-0.198***
Lower secondary or primary education	-0.487***	-0.432***	-0.404***	-0.389***	-0.362***	-0.360***	-0.352***	-0.368***	-0.279***	-0.271***	-0.292***	-0.254***	-0.246***	-0.220***	-0.235***
Experience	0.0179***	0.0169***	0.0147***	0.0146***	0.0147***	0.0124***	0.0143***	0.0161***	0.0138***	0.0140***	0.0129***	0.0104***	0.0113***	0.00983***	0.0109***
Experience squared	-0.0003***	-0.0003***	-0.0003***	-0.0003***	-0.0003***	-0.0002***	-0.0002***	-0.0003***	-0.0003***	-0.0003***	-0.0002***	-0.0002***	-0.0002***	-0.0002***	-0.0002***
Female	-0.154***	-0.171***	-0.172***	-0.175***	-0.153***	-0.153***	-0.156***	-0.161***	-0.157***	-0.162***	-0.173***	-0.180***	-0.177***	-0.184***	-0.172***
Occupation, ref.: Professionals															
Managers	0.070***	0.030	0.043*	0.000	0.074**	0.111***	0.097***	0.099***	0.101***	0.145***	0.151***	0.154***	0.126***	0.124***	0.117***
Technicians and associate professionals	-0.166***	-0.207***	-0.197***	-0.198***	-0.190***	-0.192***	-0.180***	-0.168***	-0.171***	-0.157***	-0.151***	-0.161***	-0.164***	-0.167***	-0.156***
Clerical support workers	-0.313***	-0.342***	-0.358***	-0.348***	-0.360***	-0.333***	-0.329***	-0.323***	-0.318***	-0.295***	-0.300***	-0.303***	-0.283***	-0.270***	-0.250***
Service and sales workers	-0.470***	-0.505***	-0.481***	-0.467***	-0.472***	-0.460***	-0.448***	-0.435***	-0.433***	-0.415***	-0.398***	-0.384***	-0.384***	-0.371***	-0.326***
Skilled agricultural, forestry and fishery workers	-0.446***	-0.495***	-0.354***	-0.436***	-0.443***	-0.462***	-0.460***	-0.454***	-0.393***	-0.366***	-0.349***	-0.349***	-0.372***	-0.421***	-0.340***
Craft and related trades workers	-0.319***	-0.349***	-0.319***	-0.331***	-0.338***	-0.343***	-0.335***	-0.309***	-0.318***	-0.276***	-0.252***	-0.271***	-0.273***	-0.256***	-0.224***
Plant and machine operators, and assemblers	-0.296***	-0.314***	-0.286***	-0.292***	-0.309***	-0.281***	-0.269***	-0.278***	-0.271***	-0.251***	-0.218***	-0.226***	-0.222***	-0.212***	-0.191***
Elementary occupations	-0.463***	-0.488***	-0.445***	-0.457***	-0.469***	-0.450***	-0.451***	-0.443***	-0.441***	-0.410***	-0.380***	-0.393***	-0.405***	-0.391***	-0.348***
Armed forces occupations	0.129**	0.110*	0.125**	0.151***	0.146**	0.102	0.0837	0.130*	0.107**	0.125**	0.143***	0.109**	0.089*	0.088*	0.090

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. *Parameters for control variables are not presented.*

Table 5: Changes in unadjusted labour input and labour quality index (y/y, %)

	unadjusted labour input			labour quality index					
				simplified Aaronson-Sullivan index				Aaronson-Sullivan index	Törnqvist index
	hours worked	number of workers	hours per worker	baseline (wage model IV)	wage model I	wage model II	wage model III	wage model IV, estimated for each year separately	wage model IV
2007	4.13	4.43	-0.29	0.11	0.18	0.16	0.13	0.17	0.05
2008	3.03	3.66	-0.60	0.02	0.29	0.26	0.07	0.07	0.04
2009	-1.06	0.43	-1.48	1.13	1.35	1.40	1.39	1.24	1.09
2010	-2.84	-2.52	-0.33	1.10	1.61	1.76	1.45	1.17	0.96
2011	0.60	0.60	0.00	-0.20	0.61	0.62	-0.07	-0.21	-0.13
2012	-0.38	0.16	-0.55	0.92	1.02	1.10	1.14	0.97	0.93
2013	-0.74	-0.14	-0.60	0.80	1.10	1.19	1.03	0.87	0.76
2014	2.27	1.77	0.49	0.46	0.72	0.77	0.60	0.46	0.46
2015	1.47	1.25	0.22	0.27	0.36	0.31	0.34	0.26	0.28
2016	0.78	0.59	0.19	0.53	0.56	0.59	0.62	0.49	0.49
2017	-0.13	1.35	-1.46	0.59	0.76	0.87	0.75	0.49	0.59
2018	-1.58	0.24	-1.82	0.51	0.57	0.54	0.61	0.40	0.53
2019	-0.26	-0.29	0.03	0.76	0.79	0.89	0.92	0.63	0.74
2020	-3.72	-0.14	-3.58	0.67	0.94	1.03	0.86	0.48	0.70
average 2007-2020	0.11	0.81	-0.70	0.55	0.78	0.82	0.70	0.53	0.54

Table 6: Decomposition of labour quality index change (the baseline approach)

	LQI change, y/y, %	contribution of education	contribution of experience	contribution of sex	contribution of occupation	rest of decompostion
2007	0.11	0.16	-0.11	-0.03	0.09	-0.01
2008	0.02	0.15	-0.05	-0.01	-0.03	-0.03
2009	1.13	0.59	0.02	-0.05	0.57	-0.01
2010	1.10	0.58	0.12	0.06	0.31	0.02
2011	-0.20	0.20	0.07	0.01	-0.46	-0.01
2012	0.92	0.39	0.05	-0.01	0.44	0.05
2013	0.80	0.43	0.05	0.01	0.31	0.00
2014	0.46	0.32	-0.04	0.00	0.19	0.00
2015	0.27	0.15	0.00	-0.04	0.18	-0.02
2016	0.53	0.28	-0.04	0.00	0.31	-0.01
2017	0.59	0.26	0.06	0.03	0.22	0.02
2018	0.51	0.22	0.05	-0.05	0.30	-0.01
2019	0.76	0.25	0.10	0.03	0.36	0.01
2020	0.67	0.26	0.18	0.05	0.20	-0.02
average 2007-2020	0.55	0.30	0.03	0.00	0.21	0.00

Table 7: Correlation of labour quality index change and its components with hours worked change and GDP growth rate

	LQI change	contribution of education	contribution of experience	contribution of sex	contribution of occupation
correlation with change in hours worked, 2007-2020	-0.67	-0.55	-0.91	-0.48	-0.45
correlation with change in hours worked, 2007-2019	-0.73	-0.69	-0.88	-0.33	-0.52
correlation with GDP growth, 2007-2020	-0.45	-0.34	-0.56	-0.40	-0.34
correlation with GDP growth, 2007-2019	-0.57	-0.61	-0.27	-0.13	-0.49

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