Supplementary Online Appendix

Technology, Skills, and Globalization: Explaining International Differences in Routine and Nonroutine Work Using Survey Data

Piotr Lewandowski, Albert Park, Wojciech Hardy, Yang Du, and Saier Wu

S1. List of Countries in PIAAC, STEP and CULS

PIAAC surveys include publicly available data representative of 37 countries. 23 in Round I: Austria, Belgium (Flanders), Canada, Cyprus (the area under the effective control of the Government of the Republic of Cyprus), the Czech Republic, Denmark, Estonia, Finland, France, Germany, Ireland, Italy, Japan, the Republic of Korea, Netherlands, Norway, Poland, Russia (w/o Moscow municipal area), Slovakia, Spain, Sweden, UK (England and Northern Ireland), United States; 9 in Round II: Chile, Greece, Indonesia (Jakarta), Israel, Lithuania, New Zealand, Singapore (only permanent residents), Slovenia, and Turkey; 5 in Round III: Ecuador, Hungary, Kazakhstan, Mexico, Peru. Moreover, the initial Round I sample for the United States was expanded with a supplementary sample which is available via the U.S. National Center for Education Statistics (NCES). This article uses this expanded sample.

The study uses STEP surveys for 9 countries: Armenia, Bolivia (four main capital cities – La Paz, El Alto, Cochabamba and Santa Cruz de la Sierra), Colombia (13 main metropolitan areas), Georgia (w/o Abkhazia and South Ossetia), Ghana, Kenya, Lao PDR (both urban and rural areas), Macedonia, and Serbia.

The CULS survey (3rd wave) includes data on individuals in six large cities in China: Guangzhou, Shanghai, and Fuzhou on the coast, Shenyang in the northeast, Xian in the northwest, and Wuhan in central China.

S2. Construction of Task Content Measures Based on US PIAAC and US O*NET

To construct the reference task content measures proposed by Acemoglu and Autor (2011), the study uses the Occupational Information Network (O*NET) database which contains extensive information on the occupations in the US. The O*NET data is merged with the US PIAAC data using the occupational crosswalks prepared by the O*NET Resource Center, the U.S. Bureau of Labor Statistics and the National Crosswalk Service Center, and adapted to the ISCO classification of occupations by Hardy et al. (2018).[1] ISCO is used in PIAAC, and 3-digit or 4-digit codes are available in the US PIAAC.[2] This procedure is applied at each level.

To calculate the task content of occupations, this study follows Acemoglu and Autor (2011). The first step standardizes the values $t_{j^O,i}$ of each task item j^O in the set of O*NET task items J^O, using the means ($\bar{t}^{US}_{j^O}$) and standard deviations ($\delta^{US}_{j^O}$) in the US PIAAC:

$$\forall_i \, \forall_{j^O \in J^O} \; t^{std}_{i,j^O} = \frac{t_{i,j^O} - \bar{t}^{US}_{j^O}}{\delta^{US}_{j^O}}, \tag{S2.1}$$

whereby i is a worker-level observation in the US PIAAC data. The set of O*NET task items, J^O, is presented in Table S2.1 in this supplementary online appendix. The second step constructs four task content measures: nonroutine cognitive analytical, nonroutine cognitive interpersonal, routine cognitive, and manual. Each task content measure is calculated as a sum of constituent task items (table S2.1), except for the manual measure which is the sum of all items that define routine and nonroutine manual task content measures in Acemoglu and Autor (2011). Each of these sums is then standardized to have a mean 0 and standard deviation 1 in the US PIAAC sample. Using one measure of manual tasks is not a limitation because the correlation between the nonroutine and routine manual tasks in the US PIAAC is very high (85% across 3-digit ISCO occupations and 88% across 2-digit occupations).[3]

1 See: www.ibs.org.pl/resources [accessed: 2017-05-04].

2 The dataset with 3-digit ISCO codes is available for researchers from NCES. The 4-digit ISCO codes are included in the restricted dataset at the American Institutes for Research who have kindly run this study's code.

3 Studies on the United States (Autor 2013) or European countries (Hardy et al. 2018) found that routine and nonroutine manual tasks are also highly correlated over time and follow similar trends.

Table S2.1. Set of O*NET Items, J^O, Used in Acemoglu and Autor (2011) Task Contents Measures

Task content measure (T)	Task items (J)
Nonroutine cognitive analytical	Analyzing data/information Thinking creatively Interpreting information for others
Nonroutine cognitive interpersonal	Establishing and maintaining personal relationships Guiding, directing, and motivating subordinates Coaching/developing others
Routine cognitive	The importance of repeating the same tasks The importance of being exact or accurate Structured vs. unstructured work
Routine manual	Pace determined by the speed of equipment Controlling machines and processes Spending time making repetitive motions
Nonroutine manual physical	Operating vehicles, mechanized devices, or equipment Spending time using hands to handle, control, or feel objects, tools, or controls Manual dexterity Spatial orientation

Source: Authors' elaboration based on Acemoglu and Autor (2011).

Table S2.2. PIAAC and STEP Questions Considered for the Measurement of Particular Task Content Measures, with a Number of Variable Variants (in Brackets)

	Nonroutine cognitive analytical ($J^{P,NRCA}$)	Nonroutine cognitive personal ($J^{P,NRCP}$)	Routine cognitive ($J^{P,RC}$)	Manual ($J^{P,M}$)
Task items	Solving problems (1) Reading bills (4) Reading news (4) Reading professional journals (4) Advanced math (4) Calculating prices (4) Calculating fractions (4) Programming (4)	Supervising (1) Collaborating (1) Making speeches or giving presentations (4)	Changing order of tasks – reversed (1) Reading bills (4) Filling forms (4) Calculating fractions (4) Solving problems – reversed (1) Making speeches or giving presentations – reversed (4)	Physical tasks (1)
No. of subsets	156 221	18	4 982	1

Source: Authors' elaboration.

Note: 1 and 4 identify variables for which the study uses original questions (1), or four variants of binary variables based on cutoffs available in the original question (4). For each task content measure except the manual measure, the study considers only combinations that include at least two questions. The last row shows the number of subsets of variables considered for a given task content measure.

PIAAC and STEP surveys provide data on the job tasks performed by workers. The first step of the process identified the set of potential items, $J^P = \{J^{P,NRCA}, J^{P,NRCP}, J^{P,RC}, J^{P,M}\}$, that are available in both surveys in the identical or almost identical form, and which could potentially be used to derive particular task content measures (see table S2.2 in this supplementary online appendix, and table S3.1 for the full wording of questions and allowed answers). The study chose between three and eight potential items for particular task content measures, except the manual content for which only one item ("working physically") is available in both STEP and PIAAC. The procedure reverses the values of three variables considered for the routine cognitive measure ("changing order of tasks," "solving problems,"

Table S2.3. OLS Regressions of Task Measures on Sets of Control Variables and a STEP Dummy

	Nonroutine cognitive analytical	Nonroutine cognitive personal	Routine cognitive	Manual
Base model, total sample of 42 countries				
STEP dummy	−0.22***	−0.03	−0.05	−0.38***
Base model, subsample of 39 countries with literacy assessment data				
STEP dummy	−0.17**	−0.08	−0.17	−0.39***
Base model + controls for literacy skills and for GDP per capita, subsample of 39 countries with literacy assessment data				
Literacy skills level: 0 and 1	−0.10***	−0.04***	−0.02	0.02
Literacy skills level: 3	0.08***	0.05***	−0.09***	−0.14***
Literacy skills level: 4 and 5	0.16***	0.11***	−0.22***	−0.30***
GDP per capita	−0.95	−1.51***	1.41	0.27
GDP per capita squared	0.05	0.08***	−0.07	−0.01
STEP dummy	−0.00	0.06	−0.07	−0.18***

Source: Authors' estimations based on PIAAC, STEP, CULS, and World Bank data.
Note: The base regressions include dummies for gender, 10-year age groups, education, 1-digit occupations and sectors. To save space, the chart reports only the coefficients for the STEP dummy, literacy skills, and GDP per capita (in 1000s, in PPP, current international $, country averages for 2011–2016). The regressions with literacy scores exclude China (CULS), Laos, and Macedonia due to the lack of literacy skills assessment in these countries. The total number of observations equals around 155,500 for the base model regression with all countries and around 144,500 for the specifications without China (CULS), Laos, and Macedonia. The standard errors are clustered at a country level.

Table S2.4. Cross-Country Standard Deviations of Survey and O*NET Based Occupation-Level RTI

	ISCO 1	ISCO 2	ISCO 3	ISCO 4	ISCO 5	ISCO 7	ISCO 8	ISCO 9
Survey	0.285	0.268	0.235	0.225	0.248/0.242	0.237	0.261	0.218/0.212
O*NET	0.120	0.119	0.121	0.097	0.425/0.173	0.186	0.132	0.216/0.209

Source: Authors' calculations based on PIAAC, STEP, and CULS data.
Note: For ISCO 5 and ISCO 9, additional results are shown after the O*NET outliers (ISCO 521, ISCO 951, ISCO 952) are excluded from the sample.

Table S2.5. Pair-Wise Correlations between Task Content Measures across 3-digit ISCO Occupations in the United States

	Nonroutine cognitive analytical	Nonroutine cognitive personal	Routine cognitive	Manual
Acemoglu and Autor (2011) measures based on O*NET				
Nonroutine cognitive analytical	1			
Nonroutine cognitive personal	0.71	1		
Routine cognitive	−0.35	−0.54	1	
Manual	−0.64	−0.55	0.32	1
Survey measures based on US PIAAC				
Nonroutine cognitive analytical	1			
Nonroutine cognitive personal	0.64	1		
Routine cognitive	−0.49	−0.57	1	
Manual	−0.57	−0.58	0.42	1

Source: Authors' calculations based on PIAAC and O*NET data.
Note: Correlations between occupation-level averages in the case of survey measures. Weighted by employment level at the 3-digit ISCO level.

"giving presentations"), so the higher the value is, the less common is a given phenomenon. To ensure comparability between STEP and PIAAC data, the answers are rescaled to achieve the same value ranges. In particular, for PIAAC questions with five possible answers, except for "changing the order of tasks," "solving problems," and "giving presentations," the study considers four variants of binary variables, based on cutoffs available in the original answers (see S3 for details).

The selection of questions is based on the similarities between PIAAC / STEP items and the O*NET items, and attributes of a particular type of work (Autor 2013). It is also consistent with the selections

of Lo Bello et al. (2019); de la Rica, Gortazar, and Lewandowski et al. (2020), or Marcolin et al. (2019), shown in table S4.1 in this supplementary online appendix, with three distinctions. First, those studies used either STEP data or PIAAC data and could have used any questions available in a given survey. These two datasets are combined so that it is possible to use only questions present in both surveys. Second, due to data availability, a manual task measure is constructed while Lo Bello et al. (2019) were able to distinguish between nonroutine and routine manual tasks based on STEP data. Third, in those studies, the task measures were constructed arbitrarily, while the procedure searches for subsets of questions and cutoffs that provide the best proxy for the O*NET tasks in the United States. While this method ends up with a similar number of items per task, the approach allows selecting the task items on the basis of objective criteria.

Formally, the procedure considers every subset of different questions allowed for a particular task measure:

$$t \in T \;=\; \left\{ x_{c_1}^{j_1}, \ldots, x_{c_l}^{j_k} : 2 \leq k \leq r_R,\, j_1 \neq j_2 \neq \cdots \neq j_k,\, j_i \in J^{P,R} \right\} \tag{S2.2}$$

Where r_R is the number of questions considered for particular task content $R \in \{NRCA,\ NRCP,\ RC,\ M\}$ (table B2), l is the number of variable variants c available for each question (1 or 4), and x are the values. This procedure does not allow two variants of the same question in a given subset and considers only subsets with at least two variables. The total number of subsets considered for particular task content measures is shown in table S2.2.

In the next step, the study adapts the Acemoglu and Autor (2011) methodology to the PIAAC items. It standardizes the worker-level values $x_{c_l,i}^{j_k}$ using the means ($\bar{t}_{x_{c_l}^{j_k}}^{US}$) and standard deviations ($\delta_{x_{c_l}^{j_k}}^{US}$) in the United States:

$$\forall_i \, \forall_{j_{c_l}^k \in J^{P,R}} \; x_{c_l,i}^{j_k,std} \;=\; \frac{x_{c_l,i}^{j_k} - \bar{t}_{x_{c_l}^{j_k}}^{US}}{\delta_{x_{c_l}^{j_k}}^{US}}, \tag{S2.3}$$

For each subset, the procedure sums these standardized values and standardizes those sums again within the U.S. dataset. It then calculates (weighted) averages of these subset-specific values at the level of 3-digit and 4-digit ISCO occupations. Finally, it calculates the correlations between these occupation-specific averages and the relevant O*NET-based task content measures across 3-digit and 4-digit ISCO occupations in the United States.

For each task content measure, the following criteria are used to select the best subset of PIAAC items:

- Five subsets are considered with the highest correlations with the relevant O*NET-based measure at the 3-digit or the 4-digit level of ISCO.
- A particular subset can be preferred over a subset with a higher correlation at the 4-digit level only if it has a higher correlation at the 3-digit level.
- The reversed version of variables used in the measure of routine cognitive tasks should use the same cutoffs as the original variables used in the measures of nonroutine cognitive tasks.
- The procedure allowed a change in the cutoffs if it increased the correlation at a 3-digit occupation level without a meaningful drop in the correlation at a 4-digit level, and if it mitigated any systematic differences between the task content measures calculated in PIAAC and STEP surveys.

To verify whether the values of task contents do not depend on the data source (PIAAC or STEP), the procedure estimates a range of OLS regressions. In the base model, it regresses (OLS) each task content measure against individual characteristics (gender, 10-year age groups, education, 1-digit occupations, sectors) and the STEP survey fixed effect which turns out negative and significant for all tasks except nonroutine cognitive personal (table S2.3). When the procedure controls for the level of literacy skills and

GDP per capita,[4] the difference between STEP and PIAAC remains significant only in the case of manual tasks. This shows the survey measures of cognitive tasks are consistent and comparable between the two surveys. However, the STEP fixed effect remains significant even in the most elaborate specification. Therefore, the procedure corrects the values of manual task scores in STEP by this fixed effect (0.17 is added to the manual task score of each individual in the STEP sample).

For seven out of eight 1-digit ISCO occupations, the cross-country standard deviation of survey-based RTI is larger than the cross-country standard deviation of O*NET-based RTI (table S2.4). For managers (ISCO 1), professionals (ISCO 2), clerical workers (ISCO 4), and plant and machine operators (ISCO 8) it is larger by a factor of two or more. Only for sales and services workers (ISCO %), the cross-country standard deviations of O*NET-based RTI appear larger than those of survey-based RTI, but only because of outliers in O*NET.[5] If these outliers are removed from the sample, the cross-country differences in occupational RTI are greater when using the survey-based measure than when using the O*NET-based measure in all occupations.

The survey measures also exhibit pair-wise correlations that are consistent with those exhibited by Acemoglu and Autor (2011) measures (table S2.5). The nonroutine cognitive measures are strongly and positively correlated with each other and negatively correlated with the routine cognitive and manual measures.[6] The moderate positive correlation between the routine cognitive and manual measures is also very close to those calculated using the O*NET-based measures. This supports the validity of the survey-based RTI despite its lacking manual tasks.

S3. Relevant Task Items in PIAAC and STEP Surveys

To ensure comparability between STEP and PIAAC data, the answers are rescaled to achieve common answer scales in both surveys. The PIAAC questions typically refer to the frequency ofperforming a task (five levels ranging from ‘never’ to ‘every day’), while many STEP questions refer to whether the responders normally perform a specific task as part of their job or not. Out of 16 questions that are considered, two have five available answers in both PIAAC and STEP, and two have "Yes/No" answers in both PIAAC and STEP. For these questions, the study uses original variables. For 10 questions that have five available answers in PIAAC but a "Yes/No" answer in STEP, PIAAC variables are converted into four variants of dummy variables based on the cutoffs in original answers. For two questions that have five available answers in PIAAC and 10 available answers in STEP, the STEP answers are recoded into a 1 to 5 scale (1 and 2 to 1, 3 and 4 to 2,…, 9 and 10 to 5). The procedure also corrects the item indicating supervising other workers in the STEP data so that only individuals with co-workers are allowed to supervise others.[7] In the PIAAC data, all of the self-employed responders who had no other

4 The literacy skills tests in STEP and PIAAC follow the same methodology and are comparable.

5 The high standard deviation of routine cognitive tasks based on O*NET is driven by negative outliers: occupations 521 (Street and Market Salespersons), 951 (Street and Related Services Workers), and 952 (Street Vendors, excluding food). If these outliers are ignored, the standard deviation of routine cognitive tasks turns out to be the lowest among the O*NET based measures (0.97), similarly to this study’s measures.

6 This should alleviate the concerns related to the use of “Making speeches or giving presentations” variable in both the nonroutine cognitive personal measure and the routine cognitive measure. The negative correlation between these measures is virtually identical to the one characterizing the Acemoglu and Autor (2011) measures.

7 Some respondents in STEP indicated supervising other workers despite declaring that they worked alone. The change corrects this in cases where respondents indicated any of the following combinations: a) being self-employed with no hired workers, b) being self-employed with no unpaid or paid workers, c) being the only paid worker at the current job or that the total number of people working at the organization equals one (the respondent). This problem is not present in CULS.

Table S3.1. The Considered Task Items, Their Exact Wordings and Possible Answers in PIAAC and STEP Surveys

Task item name	PIAAC		STEP	
	Question	Answers	Question	Answers
	In your job, how often do you usually…	1. Never 2. Less than once a month 3. Less than once a week but at least once a month 4. At least once a week but not every day 5. Every day	As a regular part of this work, do you have to read the following….?	Yes / No
Reading bills	- Read bills, invoices, bank statements or other financial statements?		- Bills or financial statements	
Reading news	- Read articles in newspapers, magazines or newsletters?		- Newspapers or magazines	
Reading professional journals	- Read articles in professional journals or scholarly publications?		- Reports	
Reading manuals	- Read manuals or reference materials?		- Instruction manuals/operating manuals	
Filling forms	- Fill in forms?		As part of this work, do you fill out bills or forms?	
	In your job, how often do you usually…	As above	As a normal part of this work, do you do any of the following…?	As above
Advanced math	- Use more advanced math or statistics such as calculus, complex algebra, trigonometry or use of regression techniques?		- Use more advanced math, such as algebra, geometry, trigonometry, etc.	
Calculating prices	- Calculate prices, costs or budgets?		- Calculate prices or costs	
Calculating fractions	- Use or calculate fractions, decimals or percentages?		- Use or calculate fractions, decimals or percentages	
Programming	In your job, how often do you usually use a programming language to program or write computer code?	As above	Does your work as [OCCUPATION] require the use of software programming?	As above
Making speeches or giving presentations	How often does your job usually involve making speeches or presentations in front of five or more people?	As above	As part of this work, do you have to make formal presentations to clients or colleagues to provide information or persuade them of your point of view?	As above
Solving problems	And how often are you usually confronted with more complex problems that take at least 30 minutes to find a good solution? The 30 minutes only refers to the time needed to THINK of a solution, not the time needed to carry it out.	As above	Some tasks are pretty easy and can be done right away or after getting a little help from others. Other tasks require more thinking to figure out how they should be done. As part of this work as [OCCUPATION], how often do you have to undertake tasks that require at least 30 minutes of thinking (examples: mechanic figuring out a car problem, budgeting for a business, teacher making a lesson plan, restaurant owner creating a new menu/dish for restaurant, dressmaker designing a new dress)	1. Never 2. Less than once a month 3. Less than once a week but at least once a month 4. At least once a week but

Table S3.1. Continued

				not every day 5. Every day
Physical tasks	How often does your job usually involve working physically for a long period?	As above	Using any number from 1 to 10 where 1 is not at all physically demanding (such as sitting at a desk answering a telephone) and 10 is extremely physically demanding (such as carrying heavy loads, construction worker, etc.), what number would you use to rate how physically demanding your work is?	1-10
Supervising	Do you manage or supervise other employees?	Yes / No	As a normal part of this work do you direct and check the work of other workers (supervise)?	Yes / No
Collaborating	In your job what proportion of your time do you usually spend cooperating or collaborating with co-workers?	1. None of the time 2. Up to a quarter of the time 3. Up to half of the time 4. More than half of the time 5. All the time	As part of this work, how frequently do you spend time co-operating or collaborating with co-workers?	1. Never 2. Less than once a month 3. Less than once a week but at least once a month 4. At least once a week but not every day 5. Every day
Changing order of tasks	The next few questions are about the amount of flexibility you have in deciding how you do your job: To what extent can you choose or change the sequence of your tasks?	1. Not at all 2. Very little 3. To some extent 4. To a high extent 5. To a very high extent	Still thinking of your work as [OCCUPATION] how much freedom do you have to decide how to do your work in your own way, rather than following a fixed procedure or a supervisor's instructions? Use any number from 1 to 10 where 1 is no freedom and 10 is complete freedom.	1-10

Source: Authors' elaboration based on PIAAC and STEP.
Note: The PIAAC questions wordings in this table come from the International Master Questionnaire, available on the OECD website.[8] The STEP questions wordings in this table come from the English version of the Armenia STEP Skills Measurement Survey, available at the World Bank's microdata website.[9]

workers in their jobs indicated they did not supervise anyone. Since this item has a consistent wording in both surveys, the study's correction of values in STEP ensures consistency with PIAAC data.

S4. Comparison of Task Measures Based on STEP and PIAAC Data

8 See www.oecd.org/skills/piaac/BQ_MASTER.HTM [accessed: 2017-05-02].
9 See microdata.worldbank.org/index.php/catalog/2010 [accessed: 2017-05-04].

Table S4.1. Comparison of Task Measures Based on STEP and PIAAC Data

This study's measures; PIAAC and STEP		Lo Bello et al. (2019); STEP		de la Rica et al. (2020); PIAAC		Marcolin et al. (2019); PIAAC; Routine Intensity Index only
Task content	**Items**	**Task content**	**Items**	**Task content**	**Items**	**Items**
Nonroutine cognitive analytical	Reading news Reading professional journals Solving problems Programming	Nonroutine analytical	Number of types of documents read Length of longest documents typically read Solving problems Number of math tasks performed	Abstract	Advanced math Planning the activities of others Solving problems Persuading or influencing people Read professional journals	
Nonroutine cognitive personal	Supervising Making speeches or giving presentations	Nonroutine interpersonal	Supervising Contact with clients			
Routine cognitive	Changing order of tasks (reversed) Filling forms Making speeches or giving presentations (reversed)	Routine cognitive	Learning new things Autonomy Repetitiveness	Routine	Planning your own activities (reversed) Organising own time (reversed) Instructing, training, or teaching (reversed) Advising people (reversed) Making speeches or giving presentations (reversed)	Planning own activities Changing order of tasks Change how to do work Organising own time
		Nonroutine manual	Driving Repair electronic equipment			
Manual	Physical tasks	Routine manual	Operate machines or equipment Physical tasks		Using skill or accuracy with hands or fingers Physical tasks	
Methods: uniform coding in STEP and PIAAC; standardization (means and standard deviations); averages		Methods: standardization (means and standard deviations); summation		Methods: principal component analysis		Methods: averages.

Source: Authors' elaboration based on Lo Bello, Sanchez Puerta, and Winkler (2019), de la Rica et al. (2020),and Marcolin, Miroudot, and Squicciarini (2019).

S5. Other Data Sources

To estimate the cross-country regressions, the study merges the PIAAC, STEP, and CULS data with three additional variables: ICT stock per worker, number of robots per worker, and the global value chain participation.

The data on ICT capital stock come from Eden and Gaggl (2020). The data are available at the country level, except for eight countries in the sample: Armenia, Cyprus, Georgia, Ghana, Estonia, Kazakhstan, Laos, and Macedonia. The latest year available is 2011.

The data on robots come from the International Federation of Robotics (IFR), 2017 release. The latest data available are from 2016 but the study uses the average for 2011–2016 since the survey data cover this period. The IFR data are available for ISIC 4 sectors: A, B, C, D, and E (jointly), F and P. The procedure aggregates them into three broad categories: Agriculture, Industry and Services and calculates the number of robots per worker in each country / sector cell. The IFR data are unavailable for 12 countries in the sample: Armenia, Bolivia, Cyprus, Ecuador, Georgia, Ghana, Kazakhstan, Kenya, Laos, Macedonia, Mexico, and Peru.

The data on global value chain participation are sourced from the UIBE GVC INDICATORS database. The study uses the backward linkage-based measure, defined as the foreign value added share in the production of final goods and services, and the forward-linkage measure, defined as the domestic value added from the production of intermediate exports or domestic factor content in intermediate exports (Wang et al. 2017). The procedure uses the variables based on GTAP. The latest year available is 2011. The study merges the UIBE GVC INDICATORS data with the data at the country-industry level. As the sector classifications are not fully compatible, the study aggregates some of the ISIC 4 categories to broader groups: "E+O+P+Q+U" (water supply; sewerage, waste management and remediation activities; public administration and defense; compulsory social security; education; human health and social work activities; activities of extraterritorial organizations and bodies). In China (CULS) this group also includes category D (electricity, gas, steam and air conditioning supply). "G+I" (wholesale and retail trade, repair of motor vehicles and motorcycles; accommodation and food service activities); "L+M+N" (real estate activities; professional, scientific and technical activities; administrative and support service activities); and "R+S+T" (arts, entertainment, and recreation; other service activities; activities of households as employers; undifferentiated goods- and services-producing activities of households for own use). The UIBE GVC Indicators data are not available for Macedonia.

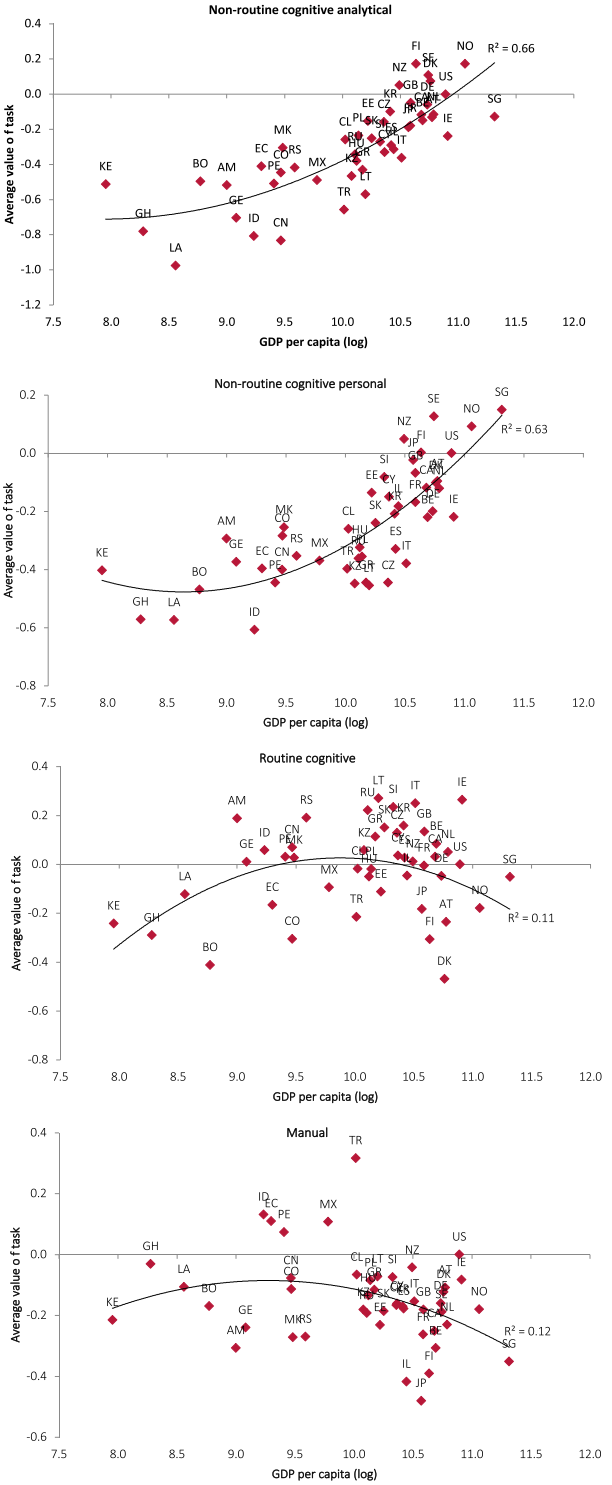
S6. Additional Descriptive Results

Substantial cross-country differences are found in the average values of particular task content measures.

In general, the more developed countries exhibit higher average values of nonroutine tasks than the less developed countries (fig. S6.1). The Nordic countries (Denmark, Sweden, Norway, Finland), most of the English-speaking countries (Canada, New Zealand, the UK and the United States) and Singapore stand out with the highest levels of nonroutine cognitive tasks. Perhaps not surprisingly, the less developed countries – Ecuador, Georgia, Ghana, Kazakhstan, Laos, Mexico, Colombia, Peru, Turkey, Indonesia, but also Lithuania and Greece – have the lowest average values of nonroutine cognitive tasks. The average value of nonroutine cognitive tasks, especially analytical tasks, is also low in China. The differences between the average values of nonroutine tasks in the highest-scoring and the lowest-scoring countries are of a magnitude comparable to one standard deviation of particular task content values among the U.S. workers.

The relationship between routine cognitive tasks and the level of development is inverse U-shaped (fig. S6.1). The least developed countries, the Nordic countries, Japan, and Austria exhibit the lowest values of routine cognitive tasks. On the other hand, central, eastern and southeastern European countries (Lithuania, the Czech Republic, Russia, Serbia, Slovakia, Slovenia) have the highest average values of

Figure S6.1. The Average Values of Tasks by Countries' Development Level (GDP per Capita).



Source: Authors' calculations based on PIAAC, STEP, CULS (tasks), and World Bank data (GDP).
Note: for each task content, the 0 is set at the US average value and 1 corresponds to one standard deviation of this particular task content value in the US. GDP per capita in PPP, current international $, country averages for 2011-2016.

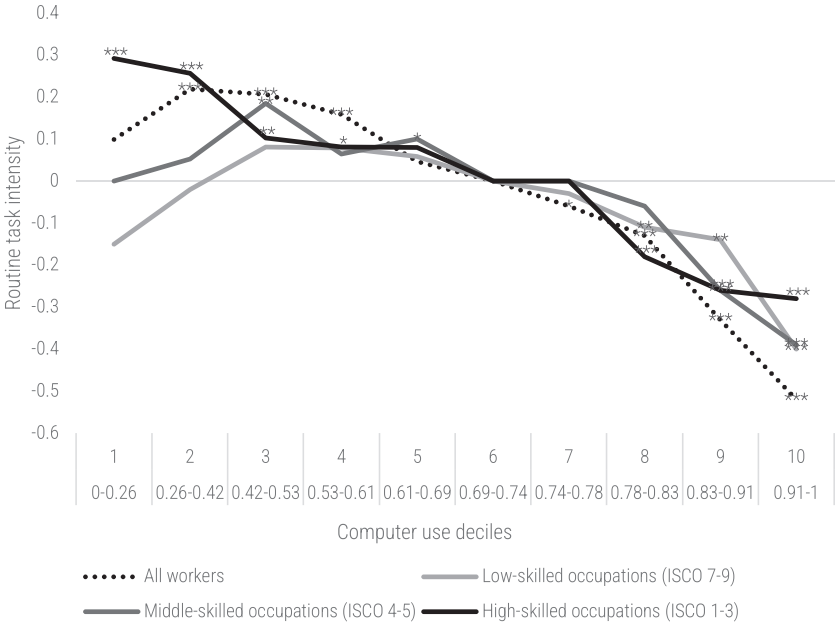
routine cognitive tasks. The values of routine cognitive tasks are also high in southern European countries (Greece, Italy), in the United Kingdom and Ireland.

The average values of manual tasks decrease with the level of development, but the relationship is less pronounced than in the case of nonroutine cognitive tasks (fig. S6.1). However, it is possible to use only one survey question to measure the manual task content, and it appears that this measure is less reliable than other task measures.[10]

10 Only five middle-income countries exhibit a higher value of manual tasks than the United States, and some middle-income countries (Armenia, Macedonia, and Georgia) are among the countries with the lowest levels of manual tasks, comparable to those in high-income countries such as Belgium and France. These differences should be interpreted with caution.

S7. Additional Regression Results

Figure S7.1. Estimated Relationship between Computer Use and RTI, for All Workers and by Occupational Group, Using the Deciles of Sector Shares of Computer Use.



Source: Authors' estimations based on PIAAC, STEP, CULS, World Bank, and UIBE GVC Indicators data.
Note: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$. Estimates from the baseline specification (2) (presented in table 4) but with decile computer use fixed effects used instead of a continous computer use variable. The 6th decile of a pooled distributon of a country-sector level computer use shares forms the reference group in all regressions. The standard errors are clustered at a sector x country level. Full estimation results are available upon request.

Table S7.1. The Estimated Interaction Terms between Sector Fixed Effects and GDP per Capita (log, demeaned), Benchmark Specification as in table 4

	All workers	High-skilled occupations (ISCO 1-3)	Middle-skilled occupations (ISCO 4-5)	Low-skilled occupations (ISCO 7-9)
Agriculture [A]	−0.134**	−0.047	−0.010	−0.198***
	(0.054)	(0.070)	(0.104)	(0.060)
Mining [B]	−0.136**	−0.057	−0.038	−0.235***
	(0.057)	(0.074)	(0.084)	(0.076)
Manufacturing [C]	0.026	0.001	0.054	−0.005
	(0.052)	(0.057)	(0.059)	(0.053)
Electricity & Water supply [D+E]	−0.119*	−0.136*	−0.093	−0.069
	(0.062)	(0.071)	(0.132)	(0.057)
Construction [F]	−0.079	−0.037	−0.062	−0.156***
	(0.049)	(0.050)	(0.082)	(0.052)
Transportation and storage [H]	0.017	0.015	−0.018	−0.035
	(0.050)	(0.057)	(0.071)	(0.053)
Accommodation and food service [I]	−0.061	0.001	−0.052	−0.060
	(0.052)	(0.069)	(0.061)	(0.056)
Information and communication [J]	0.044	0.064	0.084	0.024
	(0.056)	(0.064)	(0.063)	(0.080)
Financial and insurance [K]	−0.030	−0.034	0.043	−0.070
	(0.063)	(0.056)	(0.069)	(0.111)
Real estate & Professional [L]	−0.016	0.147*	−0.103	−0.035
	(0.062)	(0.084)	(0.069)	(0.185)
Administrative [M+N]	0.049	0.037	0.061	0.069
	(0.051)	(0.062)	(0.048)	(0.055)
Public administration [O]	0.049	0.073	0.018	0.044
	(0.062)	(0.057)	(0.080)	(0.101)
Education [P]	0.088*	0.082	0.004	−0.002
	(0.050)	(0.052)	(0.083)	(0.059)
Human health [Q]	0.001	−0.009	−0.057	−0.031
	(0.047)	(0.049)	(0.062)	(0.078)
Arts [R]	−0.022	−0.041	0.029	−0.153
	(0.063)	(0.057)	(0.060)	(0.100)
Other service [S]	−0.060	−0.142**	0.009	−0.020
	(0.052)	(0.058)	(0.052)	(0.055)
Activities of household [T]	−0.008	0.368	0.060	−0.092
	(0.079)	(0.371)	(0.059)	(0.089)
Extraterritorial organizations [U]	0.150*	0.127	−0.126	0.275
	(0.083)	(0.088)	(0.175)	(0.198)
No. of observations	166,495	68,027	52,906	45,607
R-squared	0.222	0.116	0.089	0.083

Source: Authors' estimations based on PIAAC, STEP, CULS World Bank, and UIBE GVC Indicators data.
Note: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. Standard errors in parentheses. Standardized weights are used that give each country equal weight. The standard errors are clustered at a sector x country level.

Table S7.2. The Correlates Of Routine Task Intensity (RTI) at the Worker Level, Including the Forward Linkage-Based Measure of Participation in Global Value Chains (Domestic Value Added from the Production of Intermediate Exports or Domestic Factor Content in Intermediate Exports), OLS

	All workers	High-skilled occupations (ISCO 1-3)	Middle-skilled occupations (ISCO 4-5)	Low-skilled occupations (ISCO 7-9)
Computer use	1.704***	0.971***	0.908*	2.071***
	(0.352)	(0.361)	(0.478)	(0.425)
Computer use ^ 2	−2.218***	−1.486***	−1.406***	−2.500***
	(0.297)	(0.305)	(0.420)	(0.380)
Global Value Chain (GVC) Participation (forward linkage-based)	0.258**	−0.027	0.393**	0.451***
	(0.117)	(0.110)	(0.192)	(0.166)
GVC participation * [Ln(GDP pc) –mean(Ln(GDP pc)]	−0.230**	−0.255*	−0.356**	−0.111
	(0.115)	(0.139)	(0.173)	(0.132)
FDI / GDP	0.002	0.014**	−0.005	−0.016**
	(0.005)	(0.006)	(0.007)	(0.007)
FDI / GDP * [Ln(GDP pc) –mean(Ln(GDP pc)]	0.013	0.032**	0.048**	0.030*
	(0.013)	(0.014)	(0.022)	(0.016)
Ln(GDP per capita) – Mean(Ln(GDP per capita)	0.035	−0.019	0.037	0.082
	(0.043)	(0.044)	(0.060)	(0.052)
Education: primary	0.283***	0.148***	0.263***	0.156***
	(0.015)	(0.026)	(0.018)	(0.020)
Education: tertiary	−0.501***	−0.276***	−0.220***	−0.180***
	(0.016)	(0.016)	(0.019)	(0.034)
Literacy skills level: 1 or lower	0.096***	0.029	0.051**	0.084***
	(0.015)	(0.022)	(0.024)	(0.021)
Literacy skills level: 3	−0.130***	−0.091***	−0.043**	−0.044**
	(0.012)	(0.014)	(0.019)	(0.022)
Literacy skills level: 4 and 5	−0.268***	−0.189***	−0.036	−0.164***
	(0.018)	(0.018)	(0.027)	(0.042)
Female	0.240***	0.225***	0.197***	0.339***
	(0.011)	(0.012)	(0.017)	(0.023)
Age: 16–24	0.202***	0.212***	0.182***	0.122***
	(0.016)	(0.025)	(0.023)	(0.020)
Age: 35–44	−0.056***	−0.056***	−0.025	−0.056***
	(0.010)	(0.013)	(0.016)	(0.019)
Age: 45-54	−0.021*	−0.055***	0.010	0.011
	(0.012)	(0.014)	(0.020)	(0.019)
Age: 55-65	0.022	−0.038**	0.099***	0.060***
	(0.015)	(0.018)	(0.023)	(0.022)
Sector fixed effects	Yes	Yes	Yes	Yes
No. of observations	166,495	67,986	52,902	45,607
R-squared	0.222	0.116	0.089	0.082

Source: Authors' estimations based on PIAAC, STEP, CULS World Bank, and UIBE GVC Indicators data.

Note: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$. Standard errors in parentheses. Standardized weights are used that give each country equal weight. The reference levels are: age 25–34, secondary education, wholesale and retail trade; repair of motor vehicles and motorcycles (ISIC G), lower medium literacy skills (level 2). The standard errors are clustered at a sector x country level.

Table S7.3. The Correlates of RTI, Including ICT Stock and Robot Stock per Worker, 32 Countries with Available Data, OLS Regressions

	Model with robots and ICT capital as controls (32 countries)				Benchmark specification for 32 countries with robot and ICT data available			
	All workers	High-skilled occupations (ISCO 1-3)	Middle-skilled occupations (ISCO 4-5)	Low-skilled occupations (ISCO 7-9)	All workers	High-skilled occupations (ISCO 1-3)	Middle-skilled occupations (ISCO 4-5)	Low-skilled occupations (ISCO 7-9)
Computer use	1.757***	1.064**	1.399***	1.833***	1.901***	1.359***	1.365***	1.899***
	(0.478)	(0.527)	(0.498)	(0.464)	(0.460)	(0.507)	(0.467)	(0.457)
Computer use ^2	−2.055***	−1.257***	−1.779***	−2.199***	−2.189***	−1.502***	−1.771***	−2.301***
	(0.376)	(0.433)	(0.411)	(0.394)	(0.363)	(0.419)	(0.385)	(0.388)
ICT stock per worker	−0.030**	−0.048***	−0.007	−0.028				
	(0.013)	(0.017)	(0.018)	(0.022)				
Robots per worker	−0.009	−0.025**	−0.053***	−0.017*				
	(0.009)	(0.012)	(0.016)	(0.009)				
FVA share	0.340**	−0.073	0.379***	0.837***	0.366**	−0.030	0.393***	0.863***
	(0.144)	(0.160)	(0.141)	(0.155)	(0.145)	(0.167)	(0.144)	(0.156)
FVA share * [Ln(GDP pc) –mean(Ln(GDP pc)]	−0.552***	−0.618**	−0.482**	−0.412**	−0.572***	−0.641**	−0.493**	−0.428**
	(0.192)	(0.245)	(0.191)	(0.207)	(0.193)	(0.250)	(0.193)	(0.209)
FDI / GDP	−0.344***	−0.188***	−0.438***	−0.391***	−0.343***	−0.190***	−0.424***	−0.378***
	(0.057)	(0.060)	(0.063)	(0.073)	(0.055)	(0.061)	(0.064)	(0.069)
FDI / GDP * [Ln(GDP pc) –mean(Ln(GDP pc)]	0.322***	0.221***	0.423***	0.343***	0.328***	0.233***	0.416***	0.340***
	(0.047)	(0.051)	(0.051)	(0.058)	(0.045)	(0.051)	(0.051)	(0.055)
Ln(GDP per capita) –mean(Ln(GDP per capita))	−0.046	−0.079	−0.107*	0.013	−0.076	−0.139***	−0.106*	−0.004
	(0.066)	(0.060)	(0.065)	(0.073)	(0.061)	(0.053)	(0.059)	(0.069)
Education: primary	0.298***	0.146***	0.240***	0.153***	0.297***	0.146***	0.242***	0.151***
	(0.017)	(0.029)	(0.020)	(0.020)	(0.017)	(0.029)	(0.020)	(0.020)
Education: tertiary	−0.521***	−0.294***	−0.220***	−0.213***	−0.520***	−0.294***	−0.222***	−0.210***
	(0.016)	(0.017)	(0.020)	(0.036)	(0.016)	(0.017)	(0.020)	(0.036)

Table S7.3. Continued

	Model with robots and ICT capital as controls (32 countries)				Benchmark specification for 32 countries with robot and ICT data available			
	All workers	High-skilled occupations (ISCO 1-3)	Middle-skilled occupations (ISCO 4-5)	Low-skilled occupations (ISCO 7-9)	All workers	High-skilled occupations (ISCO 1-3)	Middle-skilled occupations (ISCO 4-5)	Low-skilled occupations (ISCO 7-9)
Literacy skills level:	0.164***	0.087***	0.096***	0.136***	0.164***	0.087***	0.095***	0.136***
1 or lower	(0.016)	(0.032)	(0.024)	(0.023)	(0.016)	(0.032)	(0.024)	(0.023)
Literacy skills level: 3	−0.133***	−0.090***	−0.042**	−0.059***	−0.133***	−0.091***	−0.043**	−0.059***
	(0.012)	(0.016)	(0.021)	(0.022)	(0.012)	(0.016)	(0.021)	(0.022)
Literacy skills level: 4 and 5	−0.252***	−0.177***	−0.035	−0.169***	−0.252***	−0.178***	−0.035	−0.169***
	(0.018)	(0.021)	(0.029)	(0.039)	(0.018)	(0.021)	(0.029)	(0.039)
Female	0.268***	0.229***	0.247***	0.393***	0.268***	0.229***	0.250***	0.393***
	(0.013)	(0.012)	(0.018)	(0.027)	(0.013)	(0.012)	(0.019)	(0.027)
Age: 16–24	0.276***	0.265***	0.273***	0.157***	0.275***	0.264***	0.273***	0.158***
	(0.017)	(0.028)	(0.027)	(0.023)	(0.017)	(0.028)	(0.027)	(0.023)
Age: 35–44	−0.095***	−0.078***	−0.068***	−0.089***	−0.095***	−0.078***	−0.068***	−0.090***
	(0.011)	(0.013)	(0.020)	(0.019)	(0.011)	(0.013)	(0.020)	(0.019)
Age: 45–54	−0.079***	−0.086***	−0.038*	−0.036*	−0.079***	−0.086***	−0.036*	−0.036*
	(0.012)	(0.015)	(0.022)	(0.020)	(0.012)	(0.015)	(0.022)	(0.019)
Age: 55–65	−0.042***	−0.079***	0.074***	0.007	−0.041***	−0.079***	0.074***	0.007
	(0.015)	(0.018)	(0.027)	(0.023)	(0.015)	(0.018)	(0.027)	(0.022)
Sector fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
No. of obs.	124,023	54,904	36,422	32,697	124,023	54,904	36,422	32,697
R-squared	0.244	0.120	0.110	0.115	0.244	0.120	0.109	0.115

Source: Authors' estimations based on PIAAC, STEP, CULS, World Bank, Eden and Gaggl (2020), IFR, and UIBE GVC Indicators data.

Note: $***p < 0.01$, $**p < 0.05$, $*p < 0.1$. Standard errors in parentheses. Standardized weights are used that give each country equal weight. The reference levels are: age 25–34, secondary education, middle-skilled occupations (ISCO 4-5), wholesale and retail trade; repair of motor vehicles and motorcycles (ISIC G), lower medium literacy skills (level 2). The coefficients for sector fixed effects are not presented in order to save space and are available on request. ICT stock per worker, robots per worker, FDI and the FVA share in domestic production variables are standardized in the sample. The standard errors are clustered at a sector x country level.

Table S7.4. The Correlates of Routine Task Intensity (RTI) at The Sector Level, OLS. All Workers

Computer use	−0.587*	Female	0.188	Sector J	−0.250***
	(0.343)		(0.175)		(0.078)
Computer use ^2	−0.709**	Age: 16-24	−0.206	Sector K	−0.091
	(0.313)		(0.206)		(0.062)
Foreign Value Added share	−0.587*	Age: 35-44	0.176	Sector L	−0.101**
	(0.343)		(0.164)		(0.049)
FVA share * [Ln(GDP pc) –mean(Ln(GDP pc)]	−0.162	Age: 45-54	0.326*	Sector M+N	−0.124***
	(0.099)		(0.193)		(0.038)
FDI / GDP	−0.013***	Age: 55-65	−0.585**	Sector O	−0.120**
	(0.004)		(0.230)		(0.050)
FDI / GDP * [Ln(GDP pc) –mean(Ln(GDP pc)]	0.026	Sector A	0.000	Sector P	−0.499***
	(0.023)		(0.065)		(0.061)
Ln(GDP per capita) –mean(Ln(GDP per capita))	0.070	Sector B	−0.172	Sector Q	−0.168***
	(0.044)		(0.111)		(0.064)
Education: primary	0.046	Sector C	−0.095**	Sector R	−0.289***
	(0.160)		(0.042)		(0.046)
Education: tertiary	0.102	Sector D+E	−0.067	Sector S	−0.290***
	(0.148)		(0.075)		(0.051)
Literacy skills level:1 or lower	−0.208	Sector F	−0.252***	Sector T	0.140
	(0.207)		(0.076)		(0.121)
Literacy skills level: 3	0.010	Sector H	0.033	Sector U	−0.103
	(0.219)		(0.064)		(0.123)
Literacy skills level: 4 and	−0.700**	Sector I	−0.049		
	(0.293)		(0.046)		
No. of observations			822		
R-squared			0.806		

Source: Authors' estimations based on PIAAC, STEP, CULS World Bank, and UIBE GVC Indicators data.

Note: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. Standard errors in parentheses. All variables are calculated averages in sector s in country c. The study uses standardized weights that give each country equal weight. The reference levels are: age 25-34, secondary education, wholesale and retail trade; repair of motor vehicles and motorcycles (ISIC G), lower medium literacy skills (level 2). RTI, FDI and the FVA share in domestic production variables are standardized in the sample.

Table S7.5. The Correlates of Routine Task Intensity (RTI) at the Worker Level, Including Occupations as Controls

	All workers	High-skilled occupations (ISCO 1-3)	Middle-skilled occupations (ISCO 4-5)	Low-skilled occupations (ISCO 7-9)
Computer use	1.392***	0.927**	0.824*	1.769***
	(0.343)	(0.375)	(0.493)	(0.414)
Computer use ^2	−1.831***	−1.458***	−1.370***	−2.200***
	(0.298)	(0.316)	(0.416)	(0.376)
Foreign Value Added share	0.280***	−0.200*	0.301*	0.678***
	(0.104)	(0.114)	(0.155)	(0.134)
FVA share * [Ln(GDP pc) –mean(Ln(GDP pc)]	−0.247**	−0.252*	−0.383**	0.028
	(0.121)	(0.144)	(0.183)	(0.153)
FDI / GDP	−0.002	0.012**	−0.005	−0.019***
	(0.005)	(0.006)	(0.007)	(0.006)
FDI / GDP * [Ln(GDP pc) –mean(Ln(GDP pc)]	0.039***	0.049***	0.058***	0.013
	(0.012)	(0.014)	(0.021)	(0.017)
Ln(GDP per capita) –mean(Ln(GDP per capita))	0.005	−0.035	0.047	0.033
	(0.041)	(0.047)	(0.065)	(0.054)
Education: primary	0.177***	0.149***	0.255***	0.131***
	(0.015)	(0.027)	(0.018)	(0.020)
Education: tertiary	−0.206***	−0.219***	−0.206***	−0.145***
	(0.014)	(0.016)	(0.019)	(0.033)
Literacy skills level: 1 or lower	0.049***	0.023	0.047**	0.077***
	(0.014)	(0.022)	(0.024)	(0.020)
Literacy skills level: 3	−0.060***	−0.079***	−0.040**	−0.035
	(0.011)	(0.014)	(0.020)	(0.022)
Literacy skills level: 4 and 5	−0.137***	−0.163***	−0.032	−0.139***
	(0.015)	(0.018)	(0.027)	(0.040)
Female	0.227***	0.205***	0.207***	0.274***
	(0.011)	(0.011)	(0.017)	(0.023)
Age: 16–24	0.156***	0.188***	0.182***	0.099***
	(0.014)	(0.025)	(0.023)	(0.019)
Age: 35–44	−0.034***	−0.032***	−0.025	−0.046**
	(0.009)	(0.012)	(0.016)	(0.019)
Age: 45–54	0.004	−0.023*	0.011	0.022
	(0.011)	(0.014)	(0.020)	(0.018)
Age: 55–65	0.056***	0.000	0.101***	0.075***
	(0.012)	(0.018)	(0.023)	(0.021)
ISCO 1	−0.771***	–	–	–
	(0.021)			
ISCO 2	−0.576***	0.198***	–	–
	(0.020)	(0.017)		
ISCO 3	−0.344***	0.420***	–	–
	(0.018)	(0.016)	–	
ISCO 5	0.129***	–	0.130***	–
	(0.020)		(0.020)	
ISCO 7	0.213***	–	–	−0.416***
	(0.022)			(0.025)
ISCO 8	0.528***	–	–	−0.100***
	(0.023)			(0.024)
ISCO 9	0.596***	–	–	–
	(0.022)			
Sector fixed effects	Yes	Yes	Yes	Yes
Observations	166,495	67,986	52,902	45,607
R-squared	0.315	0.140	0.091	0.110

Source: Authors' estimations based on PIAAC, STEP, CULS, World Bank, and UIBE GVC Indicators data.

Note: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$. Standard errors in parentheses. Standardized weights are used that give each country equal weight. The reference levels are: age 25–34, secondary education, wholesale and retail trade; repair of motor vehicles and motorcycles (ISIC G), lower medium literacy skills (level 2). Clerical support workers (ISCO 4) are the reference group in the regressions for all workers, for middle-skilled occupations. Managers (ISCO 1) and Elementary occupations (ISCO 9) are the reference groups in regressions for high-skilled and low-skilled occupations, respectively. The standard errors are clustered at a sector x country level.

S8. Decomposition Results for All Countries

Figure S8.1. Regression-Based Decomposition of Differences in RTI between Particular Countries and the United States

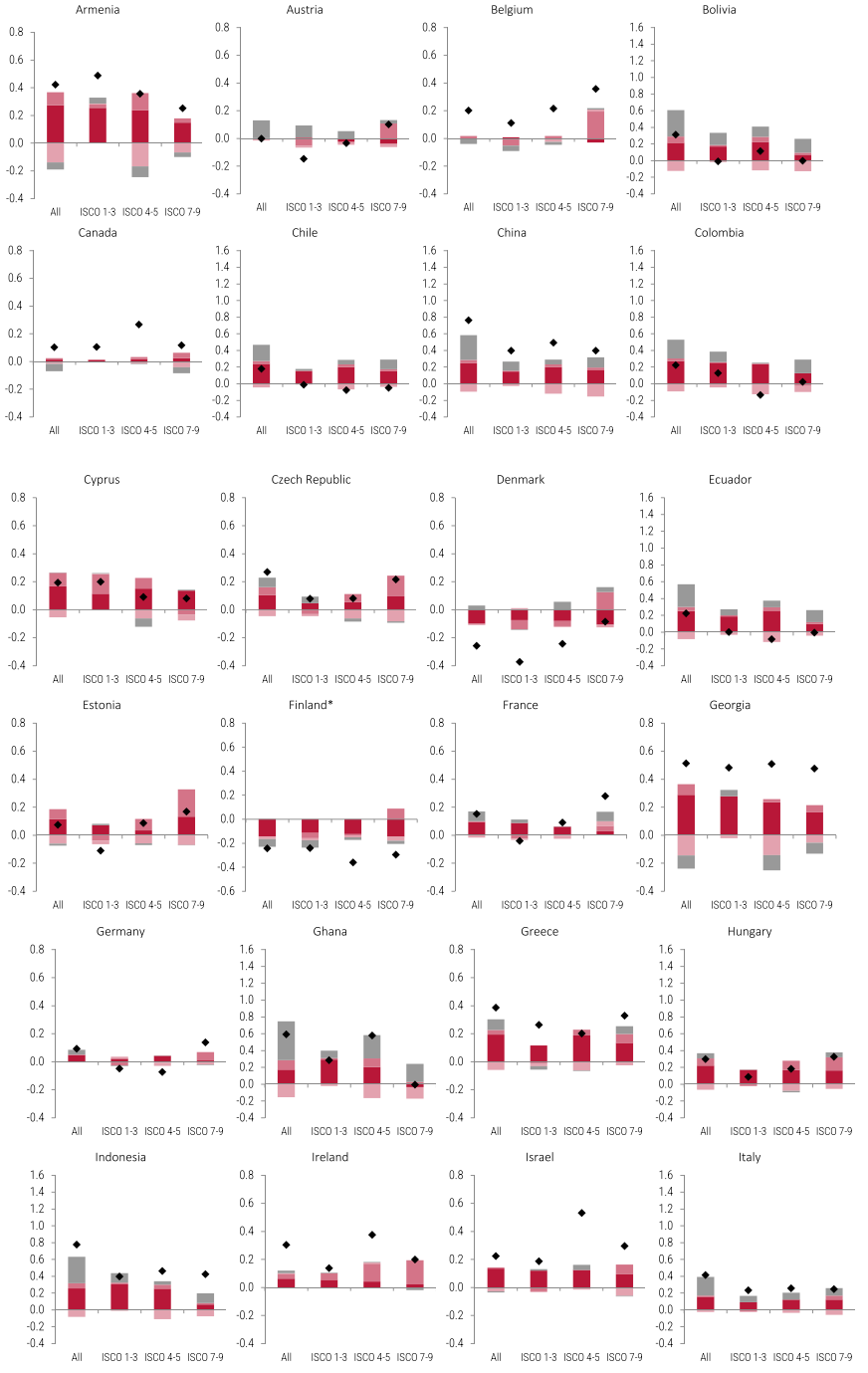
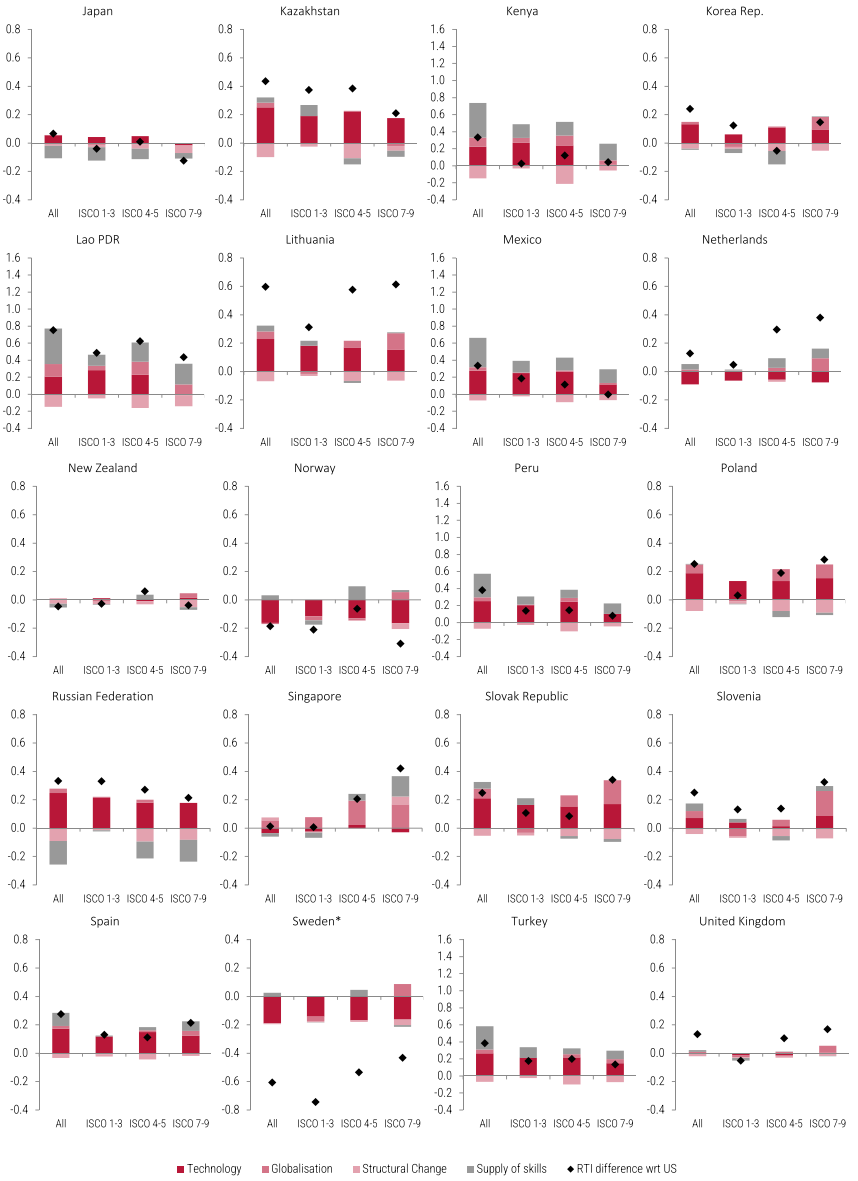


Figure S8.1. Continued



Source: Authors' estimations based on PIAAC, STEP, CULS, World Bank, and UIBE GVC Indicators data.
Note: Results of decomposition (3) based on regressions presented in table4; 0 is set at the U.S. average value and 1 corresponds to one standard deviation of RTI in the United States. For the sake of presentation, the Y-axis scale is (−0.4;0.8) for countries with relatively small differences in RTI, and (−0.4;1.6) for countries with relatively large differences in RTI. Figures for countries marked with an asterisk have different Y-axis scale.