Returns to ICT Skills

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Digitalisierung und Industrie 4.0 –
Wie verändert sich unsere Arbeitswelt?

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Motivation

- Neelie Kroes, Vice President of the European Commission (March 2014):

  "The online world is becoming a bigger part of everything we do. No wonder these [ICT] skills are becoming central in the job market. 'The new literacy.'"

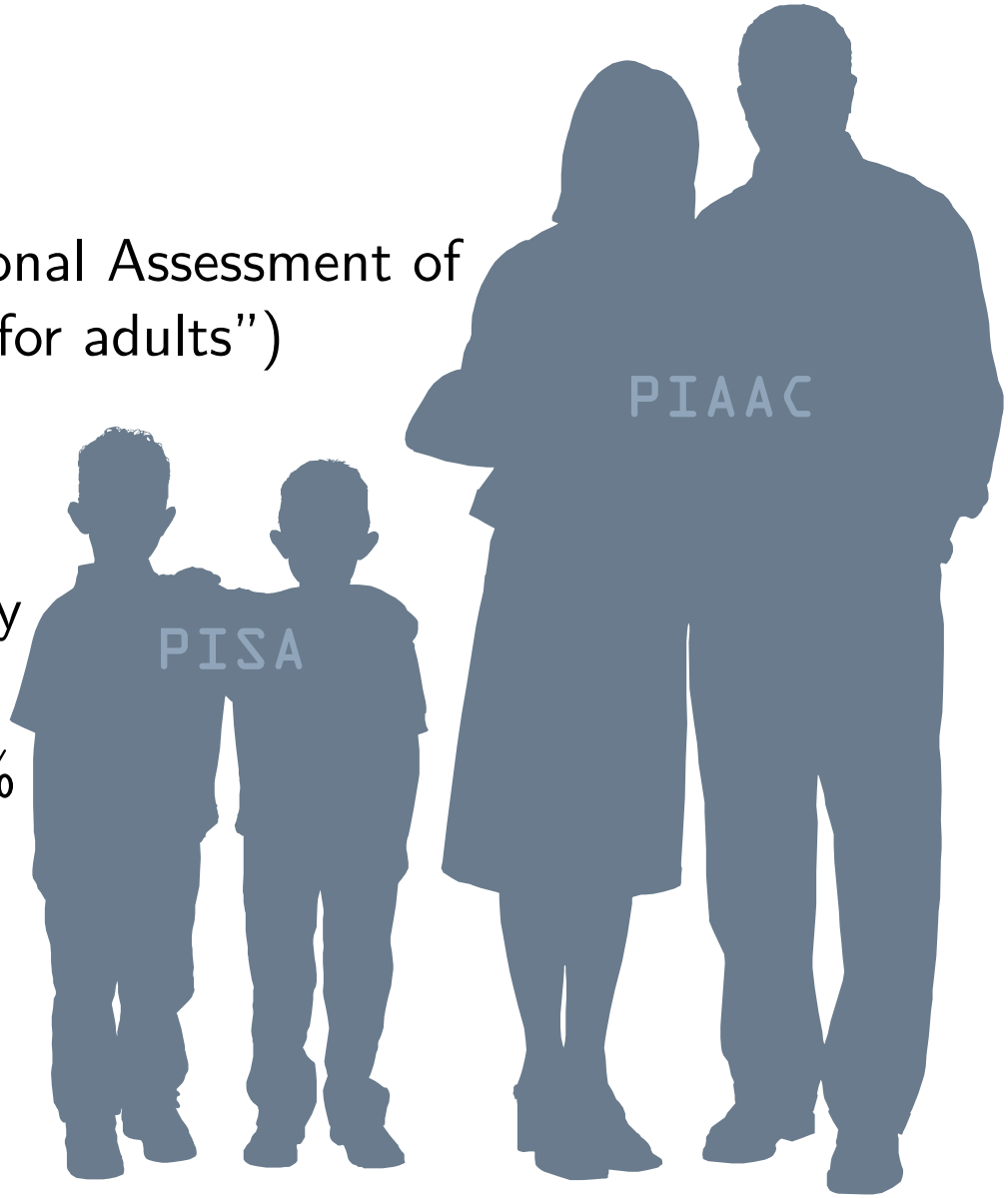
- But: No evidence on the labor-market effects of ICT skills!
- Potential reasons:
  - Lack of data
  - Lack of sources of exogenous variation in ICT skills
  - Lack of ways to disentangle individuals' ICT skills from general ability (e.g., DiNardo and Pischke, QJE 1997)

Overview

- Quantify for the first time wage returns to ICT skills
  - Use new data that allow measuring ICT skills consistently across 19 developed countries
- Use two IV strategies that exploit exogenous variation in the technologically determined probability of having Internet access
  - Underlying idea: ICT skills are developed through learning-by-doing for which Internet availability is a precondition
- Provide series of Placebo tests showing that IV approaches insulate the wage effect of ICT skills from that of other types of skills
- Investigate potential mechanisms
  - Relationship between the task content of occupations and ICT skills/computer use at work

PIAAC: Overview

- Programme for the International Assessment of Adult Competencies ("PISA for adults")
- Initiated by the OECD
- Individuals aged 16–65 yrs.
- At least N=5,000 per country (nationally representative)
- Minimum response rate: 50%



Countries participating in PIAAC Round I

Australia, Austria, Canada, ~~Cyprus~~, Czech Republic, Denmark, England/N. Ireland (UK), Estonia, Finland, Flanders (Belgium), ~~France~~, Germany, Ireland, ~~Italy~~, Japan, Korea, Netherlands, Norway, Poland, ~~Russian Federation~~, Slovak Republic, ~~Spain~~, Sweden, United States

Skill Domains

- PIAAC covers three skill domains (each measured on a 500-point scale):

1. **Problem Solving in Technology-Rich Environments**

   Use of digital technology, communication tools, and networks to acquire and evaluate information, communicate with others, and perform practical tasks
2. **Numeracy**
3. **Literacy**

- Use "Problem Solving in Technology-Rich Environments" as proxy for ICT skills

Assessment of ICT Skills

- PIAAC participants were given a series of problem scenarios
  - Had to find solution using ICT-based applications such as Internet browser, web pages, and e-mail Example
- Measured ICT skills reflect the capability of getting along in a digital world
  - Do not reflect higher-order computer skills

Sample for Cross-Country Analysis

- 19 countries (out of 24 participating in PIAAC):
  - w/o Cyprus, France, Italy, and Spain (no participation in ICT skills assessment)
  - w/o Russian Federation (Moscow region not included)
- Employees aged 20 to 49 years, no first-generation immigrants (for reasons of identification, see below)
- No self-employed
- Respondents with non-missing information on ICT skills
- 40,865 observations (from 1,357 in Slovak Rep. to 7,531 in Canada)

Descriptives Individual | Descriptives Country | Across Countries | Within Country

Estimation Equation

- Analogous to the classical Mincer equation (Mincer, 1970, 1974)

$$\ln w_{ic} = \beta_0 + \beta_1 ICT_{ic} + \beta_2 X_{ic} + \beta_3 X_c + \varepsilon_{ic}$$

w_{ic}	:	gross hourly wage of individual i in country c
ICT_{ic}	:	ICT skills (normalized with mean 0 and SD 1)
X_{ic}	:	individual-level controls (Mincer)
X_c	:	country-level controls

- β_1 measures the "return to ICT skills"

Returns to ICT Skills (OLS)

Dependent variable: log gross hourly wage	(1)	(2)	(3)	(4)
ICT skills	0.096***	0.120***	0.073***	0.059***
	(0.009)	(0.008)	(0.009)	(0.007)
Experience		0.043***	0.037***	0.036***
		(0.003)	(0.003)	(0.003)
Experience^2 (/100)		–0.080***	–0.063***	–0.062***
		(0.007)	(0.007)	(0.006)
Female		–0.121***	–0.148***	–0.159***
		(0.018)	(0.018)	(0.019)
Years of schooling			0.057***	0.066***
			(0.005)	(0.004)
Country characteristics	X	X	X	
Country fixed effects				X
R squared (adjusted)	0.35	0.45	0.50	0.53
Individuals	40,869	40,869	40,869	40,869
Countries	19	19	19	19

* p<0.10, ** p<0.05, *** p<0.01

Table Notes Country-Level Regression

Potential Sources of Bias in OLS

- Simple OLS estimations plagued by measurement error, reverse causality, and omitted-variable bias

1. **Measurement error**

   ICT skills in PIAAC just an error-ridden measure of true ICT skills
2. **Reverse causality**

   People may have higher ICT skills *because* they have a better job
3. **Omitted variables**

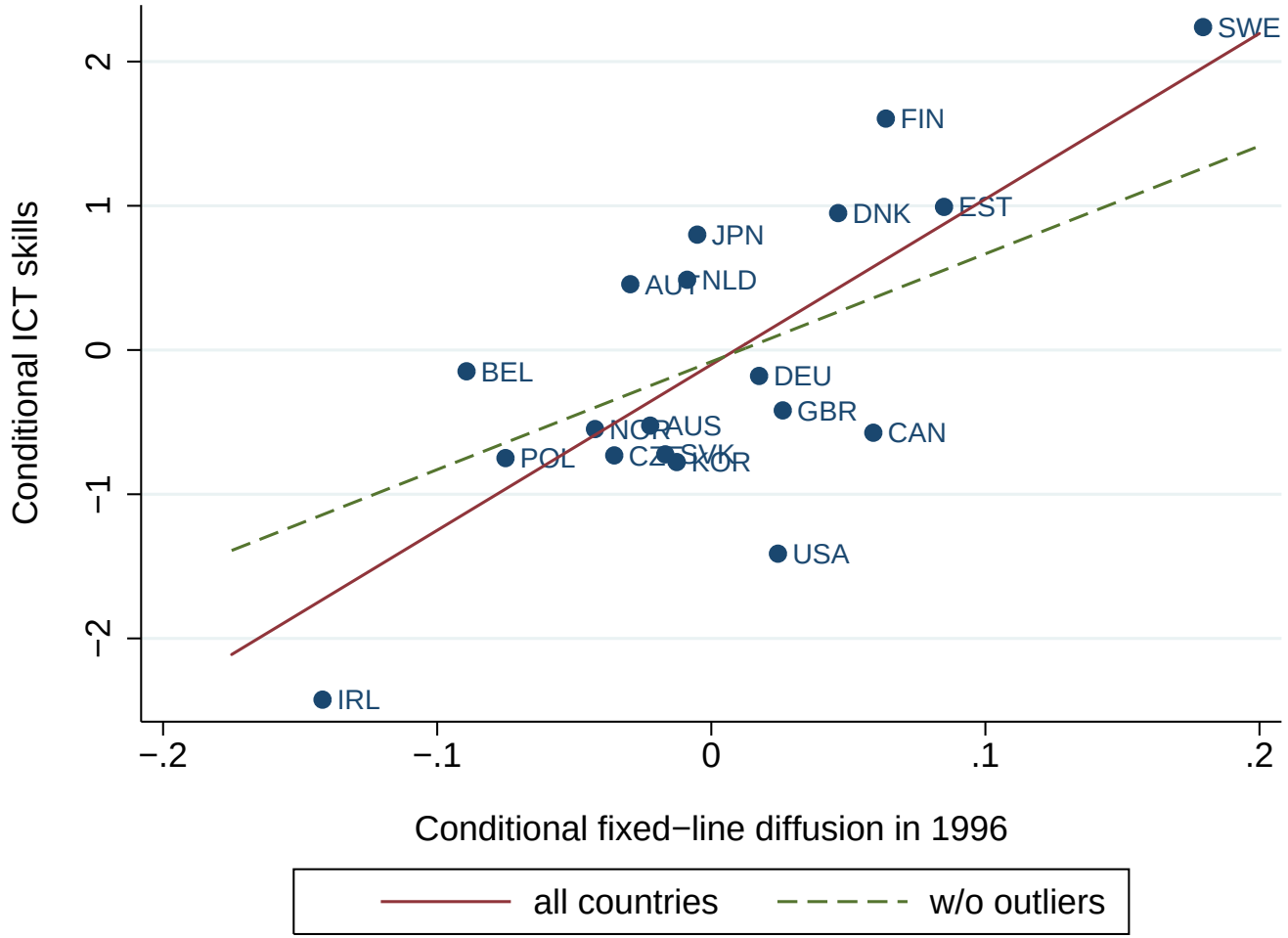
   ICT skills in PIAAC likely correlated with other cognitive skills, non-cognitive skills, personality traits, family background etc.

- To address these issues, use two IV strategies (across countries and within country)

Cross-Country IV Strategy

- Exploit exogenous variation in the probability of having Internet access across countries
- Broadband Internet relied on copper wires of the existing fixed lines
  - Countries with better-developed voice-telephony network had higher diffusion rates of broadband Internet in any consecutive year (see Czernich et al., EJ 2011) Diffusion Curves
- Idea: Persons living in a country with farther-reaching telephony network accumulated ICT skills faster
- Instrument: extent of fixed-line voice-telephony network in 1996 (i.e., before broadband rollout)
- Condition IV estimates on:
  - GDP per capita in 1996 (to account for cross-country differences before broadband rollout)
  - Average wages of exit-age workers (to account for direct effects of broadband diffusion on wages)

First Stage: Past Fixed-Line Diffusion and ICT Skills



Notes: Added-variable plot from a regression of ICT skills on fixed-line diffusion (1996) and all control variables included in Column (3) of the below IV table. Sample: employees aged 20–49, no first-generation migrants. Based on individual-level regressions that are then aggregated to the country level. Solid line is fitted through all country-level observations; for fitting the dashed line, Ireland and Sweden are excluded. *Data sources:* ITU, OECD, PIAAC.

Table | By Migration Status | By Age

Second-Stage Results

Second stage (Dependent variable: log gross hourly wage)	(1)	(2)	(3)
ICT skills	0.059**	0.053**	0.075***
	(0.026)	(0.023)	(0.012)
Experience		0.043***	0.042***
		(0.003)	(0.003)
Experience^2 (/100)		–0.071***	–0.057***
		(0.012)	(0.008)
Female		–0.101***	–0.094***
		(0.018)	(0.016)
Years of schooling			0.020**
			(0.009)
Country characteristics	X	X	X
First stage (Dependent variable: ICT skills)			
Fixed-line diffusion in 1996	6.183***	6.568***	11.601***
	(1.102)	(0.905)	(1.554)
Instrument F statistic	31.5	52.6	55.7
Individuals	40,869	40,869	40,869
Countries	19	19	19

* p<0.10, ** p<0.05, *** p<0.01

Table Notes Full Model

Placebo Test

Dependent variable: cognitive skills in	Numeracy (1)	Literacy (2)	ICT (3)	ICT (4)
Fixed-line diffusion in 1996	1.769	1.984	4.529***	3.697***
	(1.860)	(1.190)	(0.923)	(0.598)
ICT skills	0.568***	0.636***		
	(0.016)	(0.016)		
Numeracy skills			0.846***	
			(0.016)	
Literacy skills				0.844***
				(0.014)
Country characteristics	X	X	X	X
Individual characteristics	X	X	X	X
R squared (adjusted)	0.57	0.62	0.57	0.62
Individuals	40,869	40,869	40,869	40,869
Countries	19	19	19	19

* p<0.10, ** p<0.05, *** p<0.01

Table Notes

Robustness

- Additional country-level controls Results
  - Service-sector share, union density, employment-protection legislation, public-sector share, youth UR, enrollment tertiary education, cable diffusion (1996)
  - Gross fixed capital formation, ICT patents (EPA), all patents (EPA)
- Additional individual-level controls Results
  - Age or potential experience (age minus years of schooling minus 6) instead of actual experience, full-time indicator, family background, health
  - Firm size
- Occupation FE and industry FE Results
- Alternative samples
  - No post-communist countries
  - By age group, gender, education
  - Private sector vs. public sector

Within-Country IV Strategy

- Exploit peculiarities in the structure of the pre-existing voice-telephony network in Germany as a source of exogenous variation in ICT skills
- Threshold instrument (see Falck, Gold, and Heblich, AER 2014)
  - "Last mile" distance between household and main distribution frame (MDF) is crucial for DSL availability DSL Network
  - When surpassing a threshold of about 4,200 meters, DSL technology is no longer feasible
- Idea: PIAAC respondents in municipalities above the 4,200-meter threshold have lower ICT skills because of lacking high-speed Internet access
- Instrument: dummy variable that equals 1 for municipalities with distance of centroid to MDF above 4,200 meters; 0 otherwise

Within-Country Evidence: Main Results

Second stage (Dependent variable: log gross hourly wage)	Full sample			No own MDF sample		
	(1)	(2)	(3)	(4)	(5)	(6)
ICT skills	0.203***	0.201***	0.140*	0.224**	0.237**	0.190*
	(0.075)	(0.066)	(0.084)	(0.095)	(0.095)	(0.113)
Municipality characteristics	X	X	X	X	X	X
Experience and gender		X	X		X	X
Years of schooling			X			X
First stage (Dependent variable: ICT skills)						
Threshold	–0.895***	–0.824***	–0.586***	–1.259***	–1.123***	–0.807**
	(0.268)	(0.258)	(0.222)	(0.322)	(0.335)	(0.321)
Instrument F statistic	11.2	10.2	6.9	15.3	11.3	6.3
Individuals	1,417	1,417	1,417	122	122	122
Municipalities	205	205	205	18	18	18

* p<0.10, ** p<0.05, *** p<0.01

Table Notes Full Model

Within-Country Evidence: Placebo Test

Dependent variable: cognitive skills in	Numeracy	Literacy	ICT	ICT
	Panel A: Full Sample			
Threshold	0.278**	0.049	–0.502***	–0.310*
	(0.123)	(0.165)	(0.142)	(0.167)
ICT skills	0.676***	0.709***		
	(0.023)	(0.022)		
Numeracy skills			0.709***	
			(0.020)	
Literacy skills				0.754***
				(0.020)
	Panel B: No own MDF Sample			
Dependent variable: cognitive skills in	Numeracy	Literacy	ICT	ICT
Threshold	0.209	0.164	–0.616***	–0.482***
	(0.149)	(0.149)	(0.211)	(0.139)
ICT skills	0.599***	0.706***		
	(0.060)	(0.067)		
Numeracy skills			0.696***	
			(0.065)	
Literacy skills				0.801***
				(0.066)
	Controls in Panels A + B			
Municipality characteristics	X	X	X	X
Individual characteristics	X	X	X	X

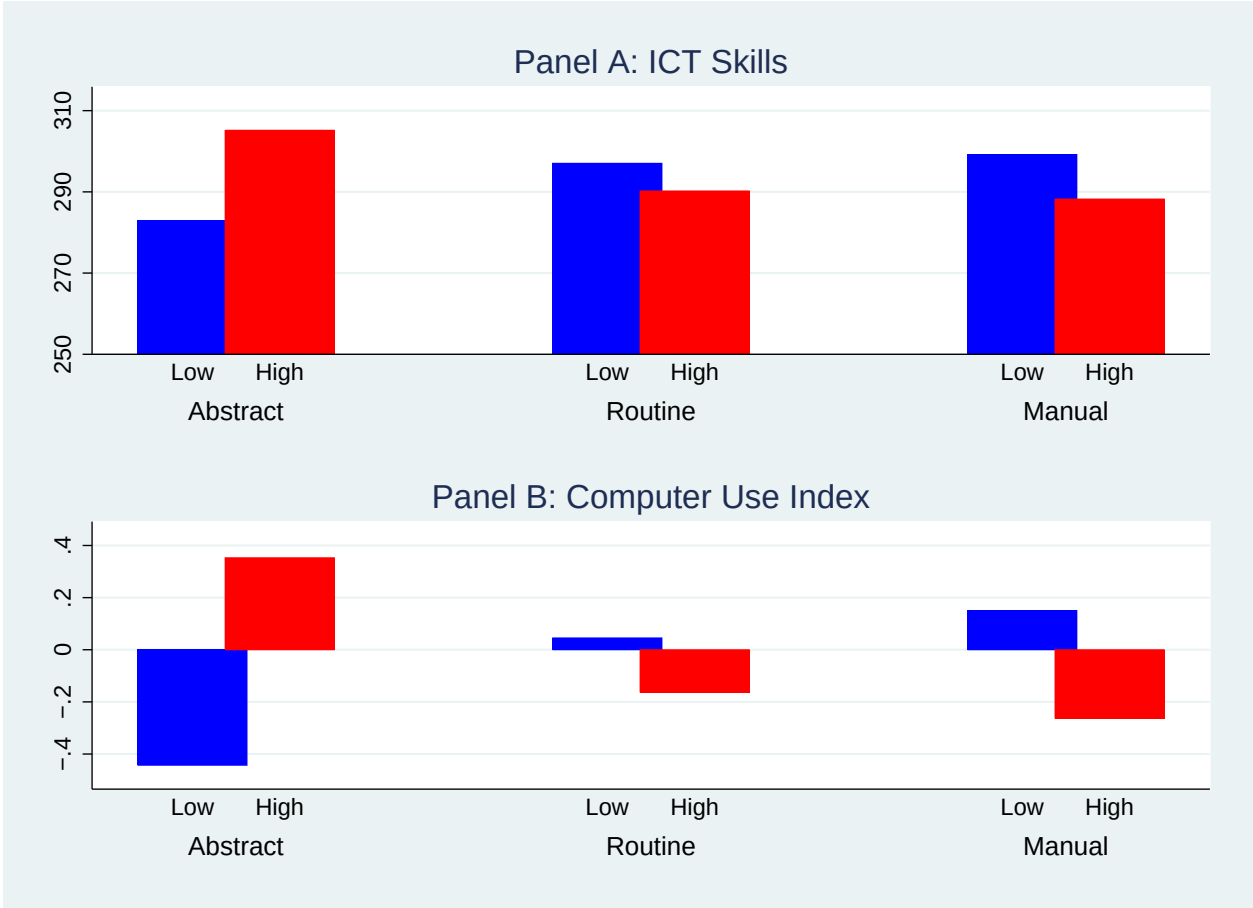
* p<0.10, ** p<0.05, *** p<0.01

Table Notes

Potential Mechanism: Task Content of Occupations

- Task-based approach developed by Autor, Levy, and Murnane (QJE 2003)
  - Assumes that personal computers substitute for routine tasks and are complementary to (nonroutine) abstract tasks
- Use information on ICT skills and computer use at work in PIAAC to investigate the role of occupational task content for returns to ICT skills
- Use population median to distinguish between workers in jobs with a high vs. low task intensity

ICT Skills and Computer Use by Task Content



Notes: Sample: employees aged 20–49, no first-generation migrants; 222 individuals who did not provide information on their occupation are also excluded. To distinguish between "high" and "low" task intensities, we use the population median in abstract, routine, and manual tasks, respectively. Task measures are taken from Goos, Manning, and Salomons (2014) and are defined at the two-digit ISCO level. Computer use index is based on questions indicating how often a person performs the following activities at work: create or read spreadsheets, use word-processing software, use programming language, and engage in computer-aided real-time discussions; answers are combined to a single index following the procedure described in Kling, Liebman, and Katz (2007) and then aggregated to the country-occupation (two-digit ISCO level) level. *Data sources:* Goos, Manning, and Salomons (2014), PIAAC.

Conclusions

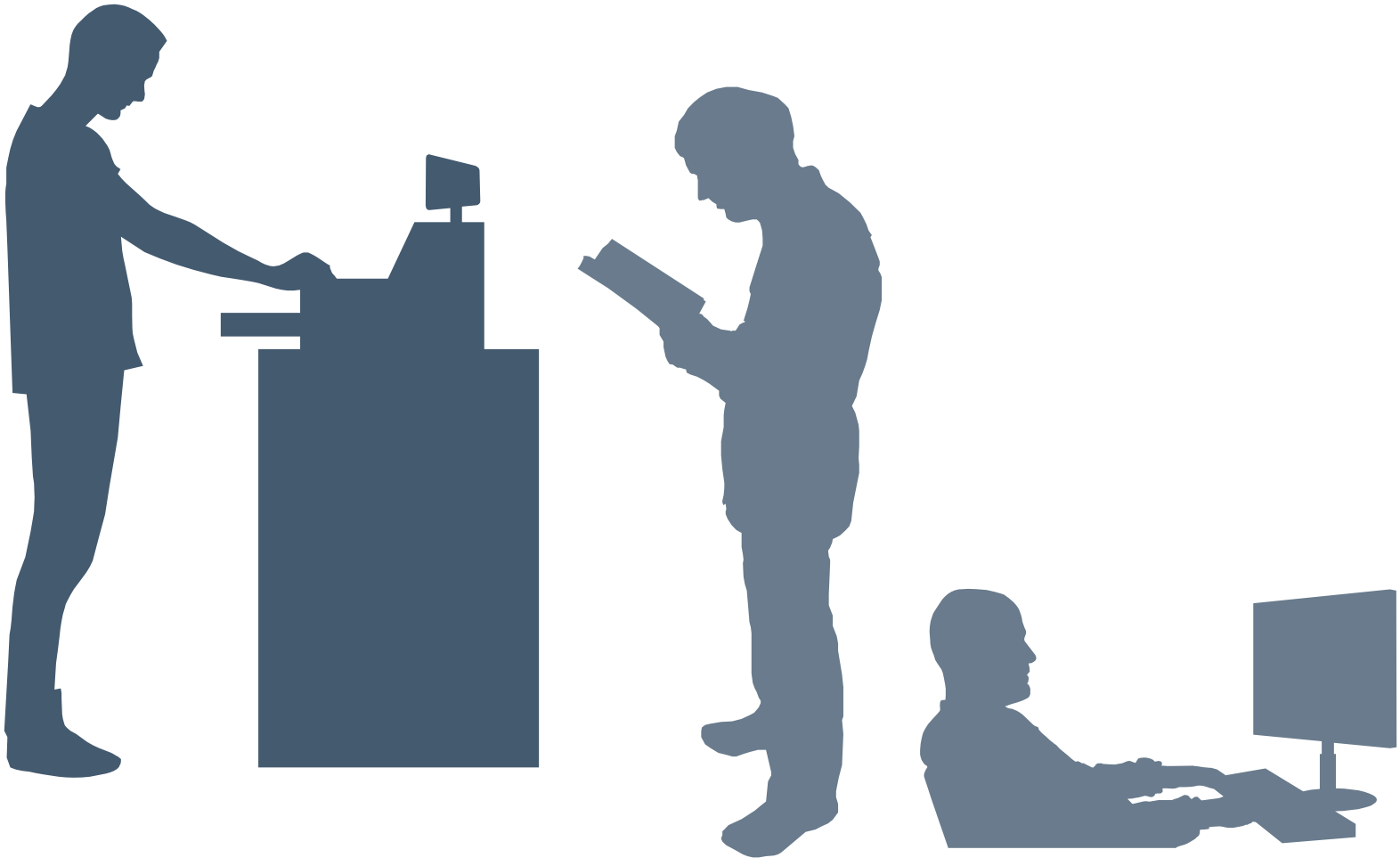
- Use new, internationally comparable, measures of ICT skills for 19 developed countries based on PIAAC data
- Use two IV approaches (across and within countries) exploiting exogenous variation in the probability to have Internet access
- Higher ICT skills are systematically related to higher wages
  - 1 SD increase in ICT skills leads to an increase in hourly wages of 7.5 percent across countries (very similar in Germany)
- Technologically determined probability of Internet access cannot explain any variation in numeracy or literacy skills
  - IV approaches successfully insulate the wage effect of ICT skills from that of other types of skills
- Proliferation of computers complements workers in executing abstract tasks, which use and reinforce ICT skills

Policy Implications

- ICT skills are likely becoming an indispensable requirement for an increasingly large part of the workforce
- Rather poor performance of some European countries in ICT skills test signals dire need for reforms
- Policies for skill development should acknowledge the learning-by-doing channel in skill accumulation

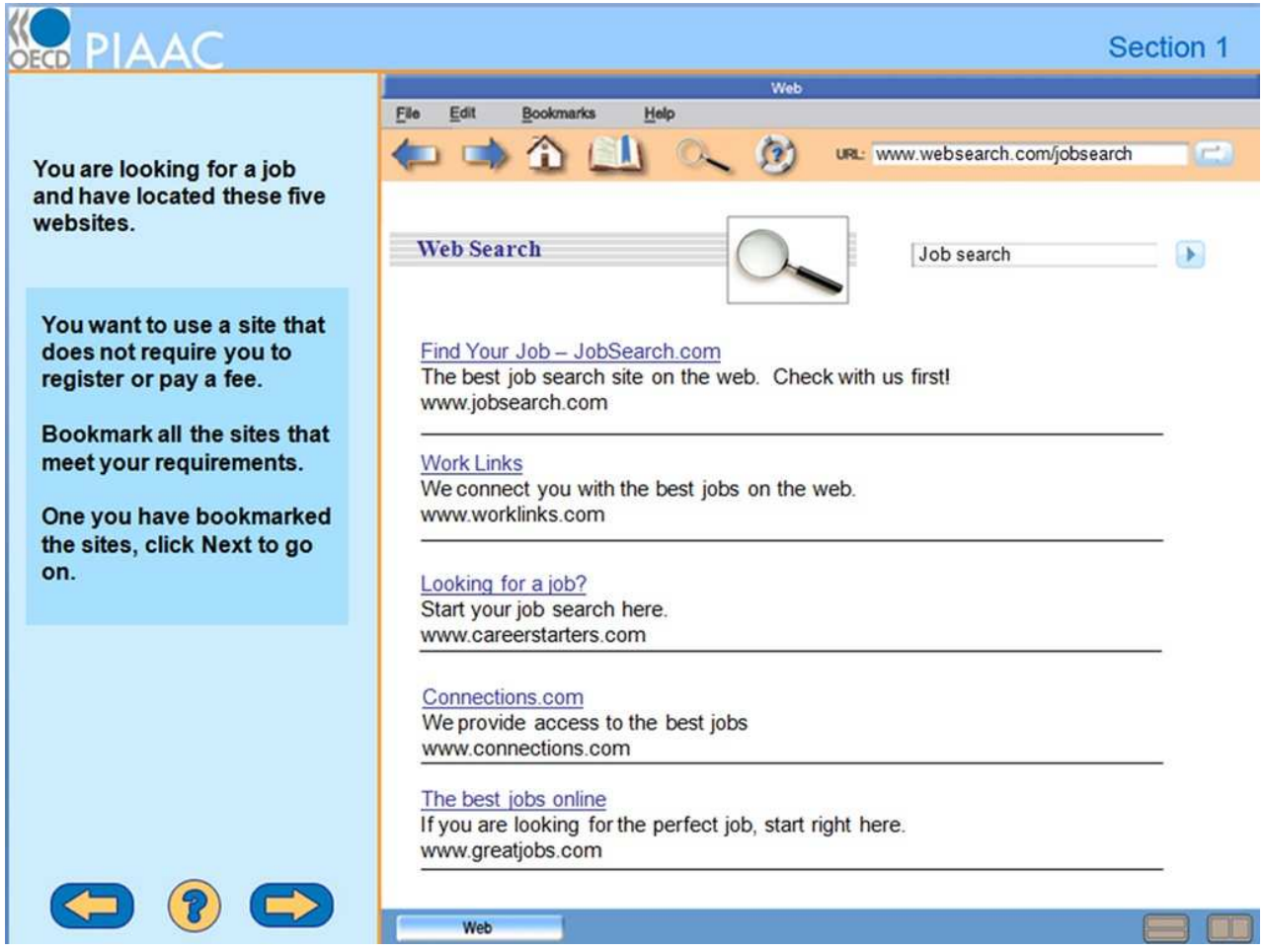
  $\Rightarrow$ EU's "Digital Agenda" may prove even more beneficial than previous research would suggest

Thanks for your attention!



Backups

Example of a Problem Scenario



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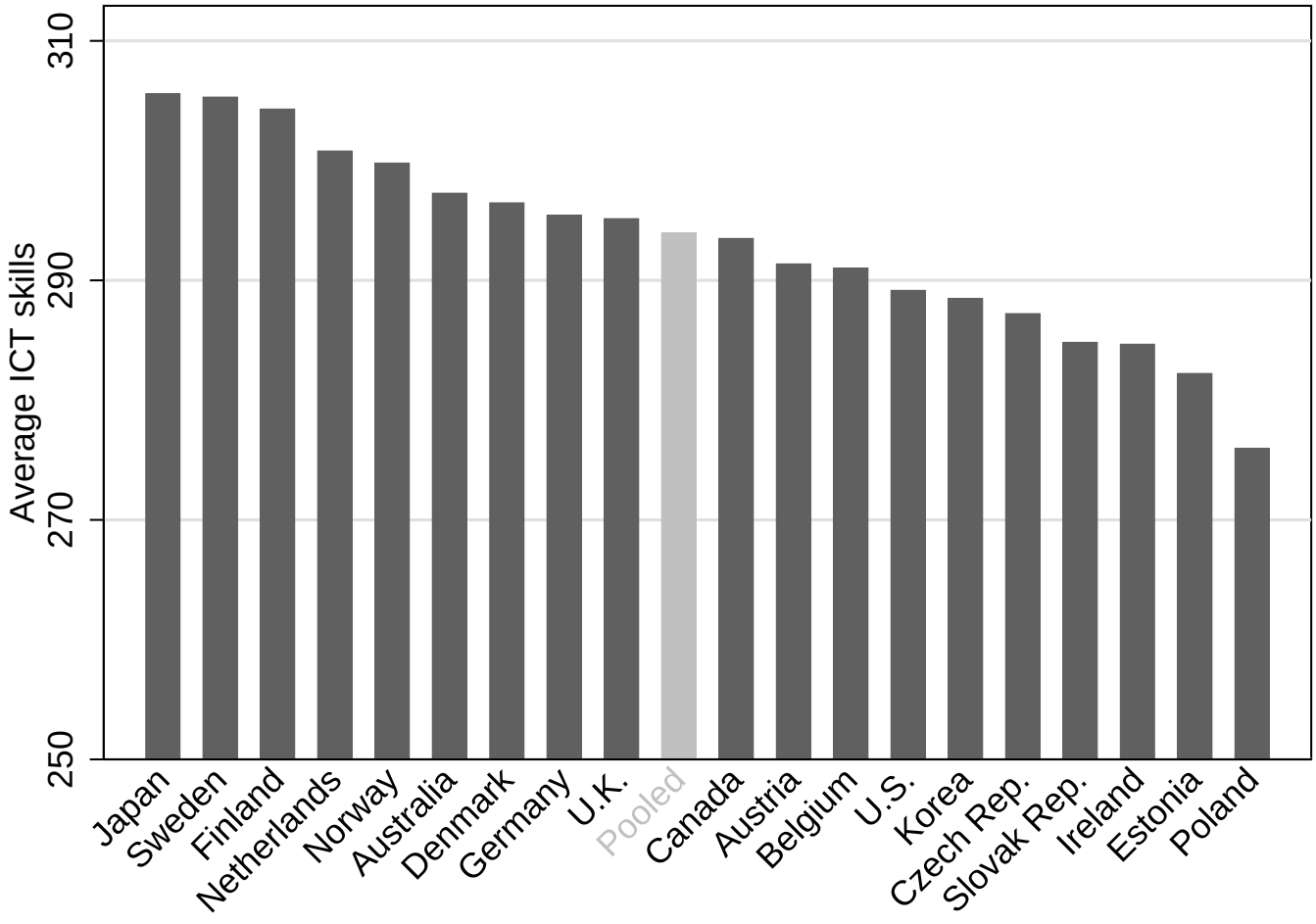
ICT Skills around the World



Notes: Average ICT skills across countries. Sample: employees aged 20–49 (no first-generation migrants). *Data source:* PIAAC.

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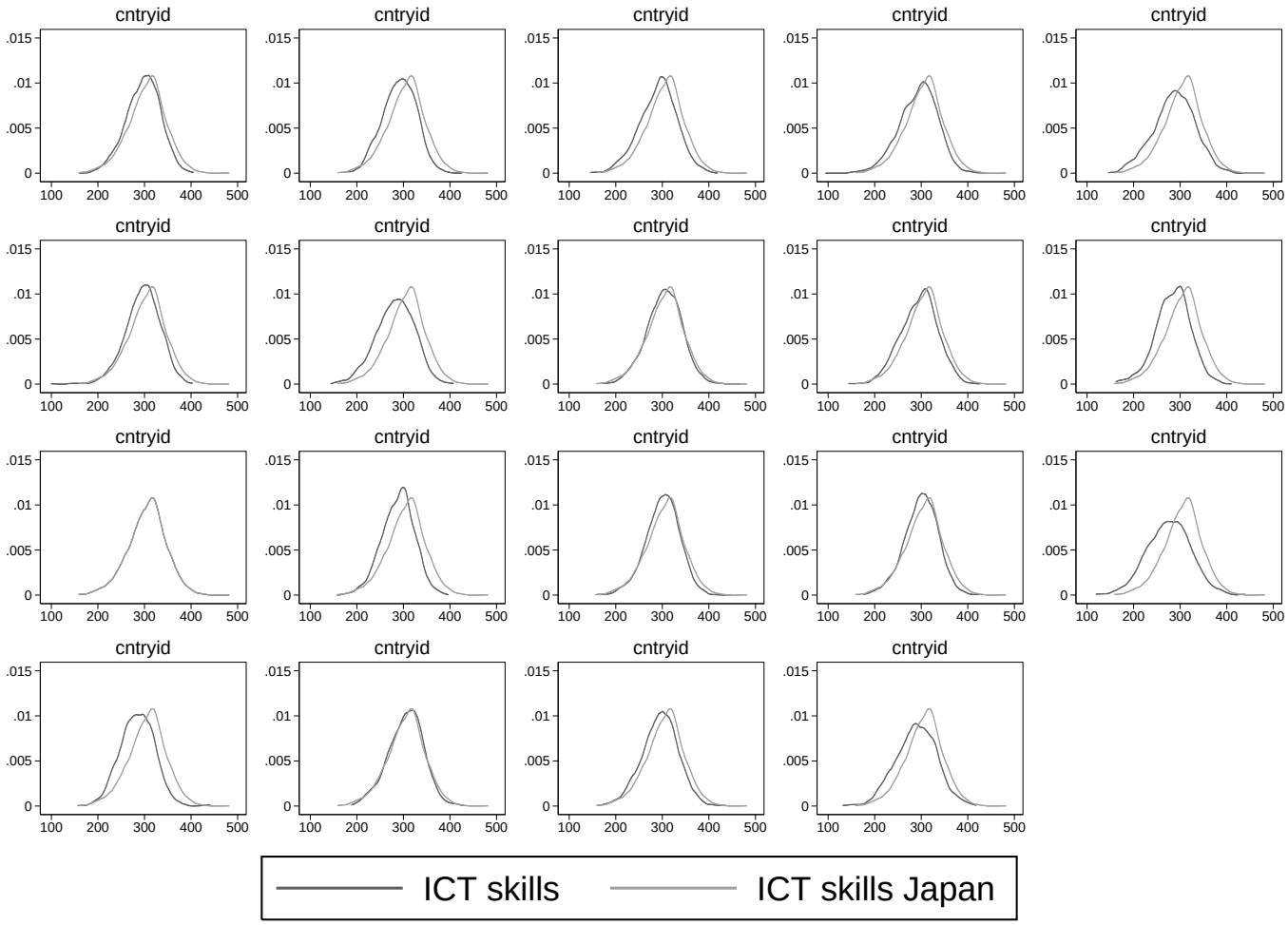
ICT Skills within Countries



Notes: Smoothed kernel density plots are shown. A kernel density plot of Japan (i.e., the country with highest average ICT skills) in shown in each panel. Sample: employees aged 20–49 (no first-generation migrants). *Data source:* PIAAC.

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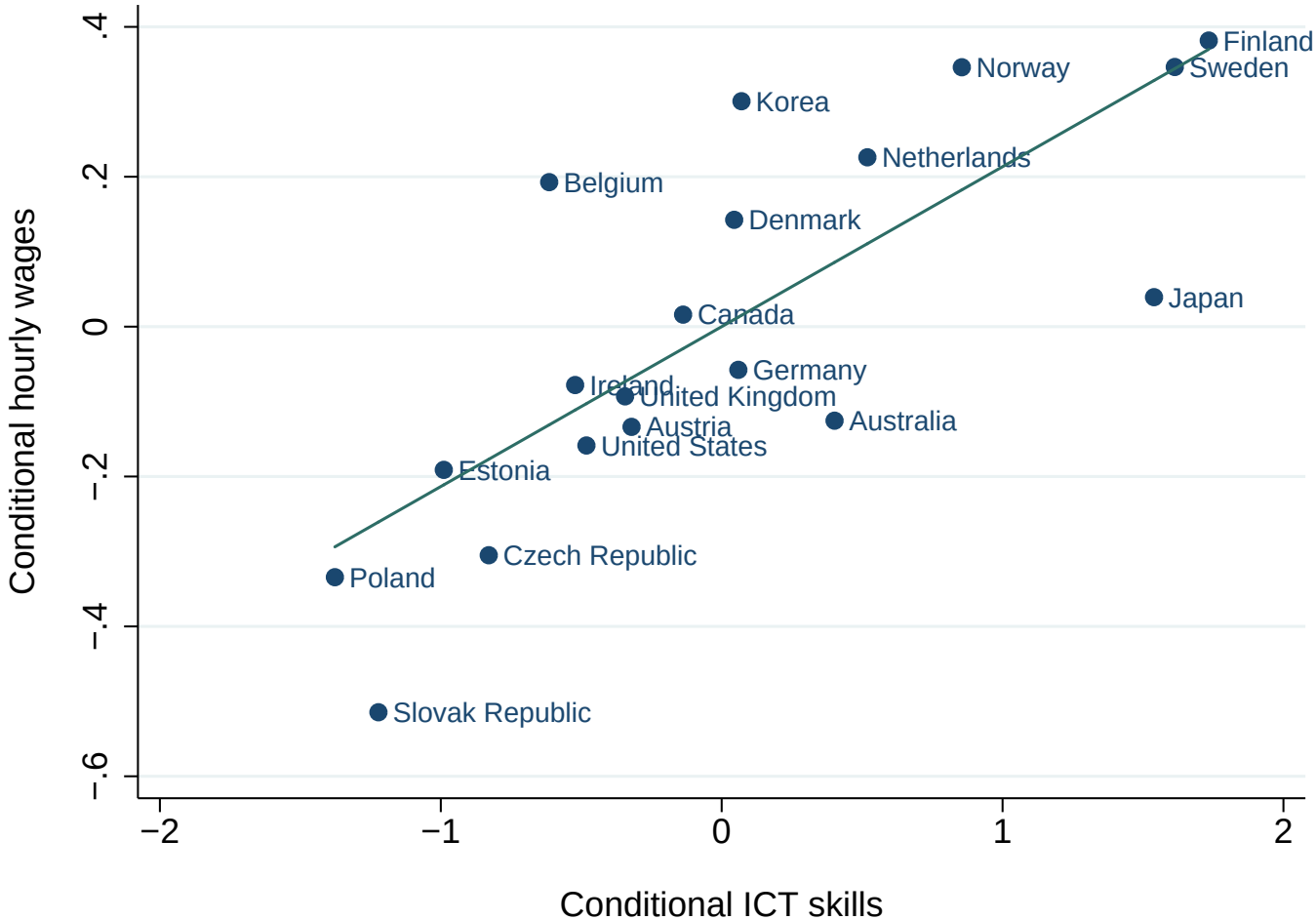
Returns to ICT Skills: Country-Level Regression



Notes: Added-variable plot of a regression of hourly wages on ICT skills, a quadratic polynomial in work experience, female indicator, and years of schooling. All variables are aggregated to the country level. "Conditional" refers to variation in wages and ICT skills, respectively, purged for variation in these other variables. Sample: employees aged 20-49, no first-generation migrants. *Data source:* PIAAC.

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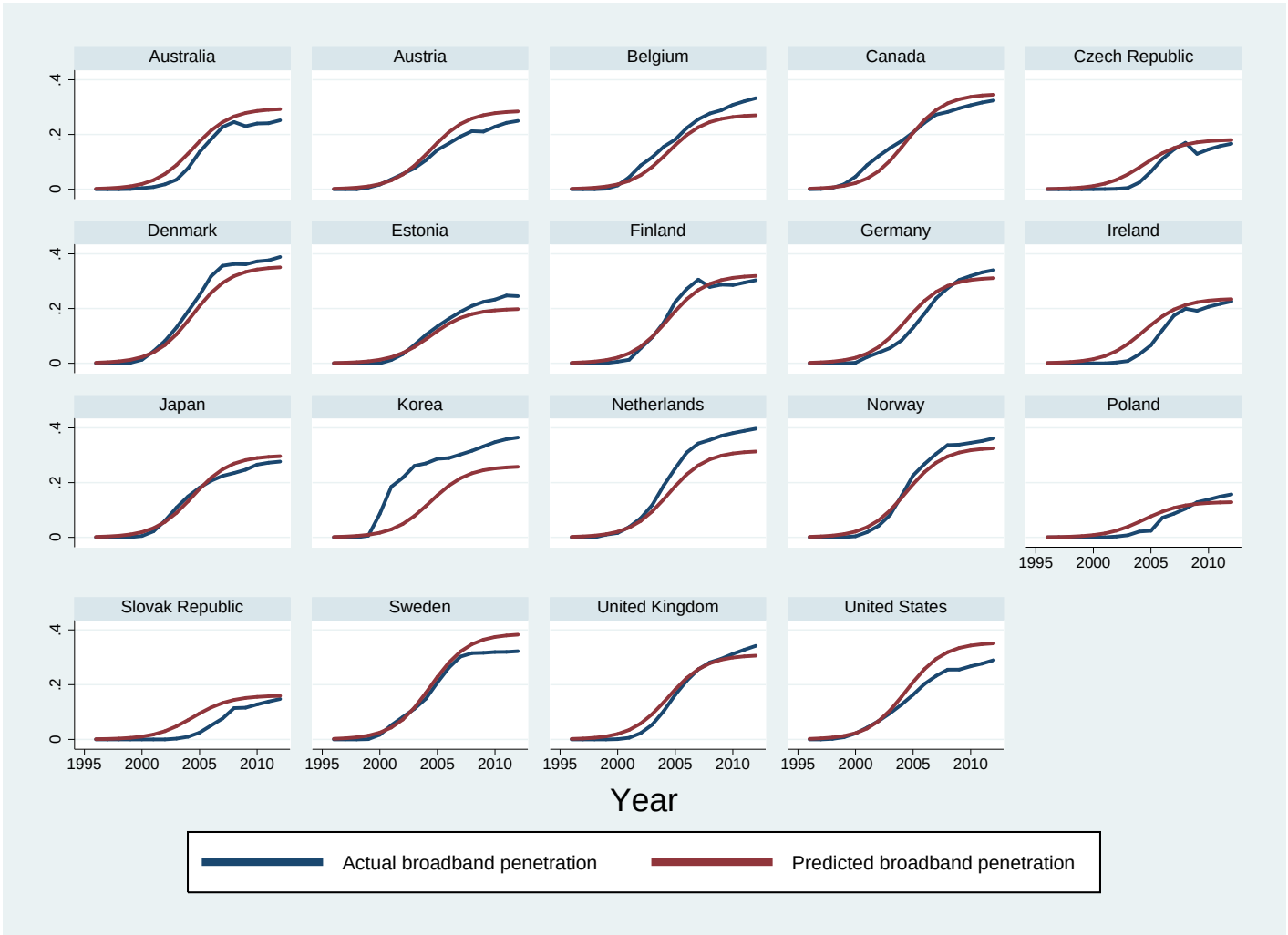
Broadband Diffusion across Countries: Actual and Predicted Curves, 1996–2012



Notes: Actual broadband diffusion: number of broadband subscribers per inhabitant. Predicted broadband diffusion is derived from nonlinear least squares estimation of a diffusion curve based on telephone access lines per inhabitant in 1996. See Section 3 for details. *Data source:* ITU.

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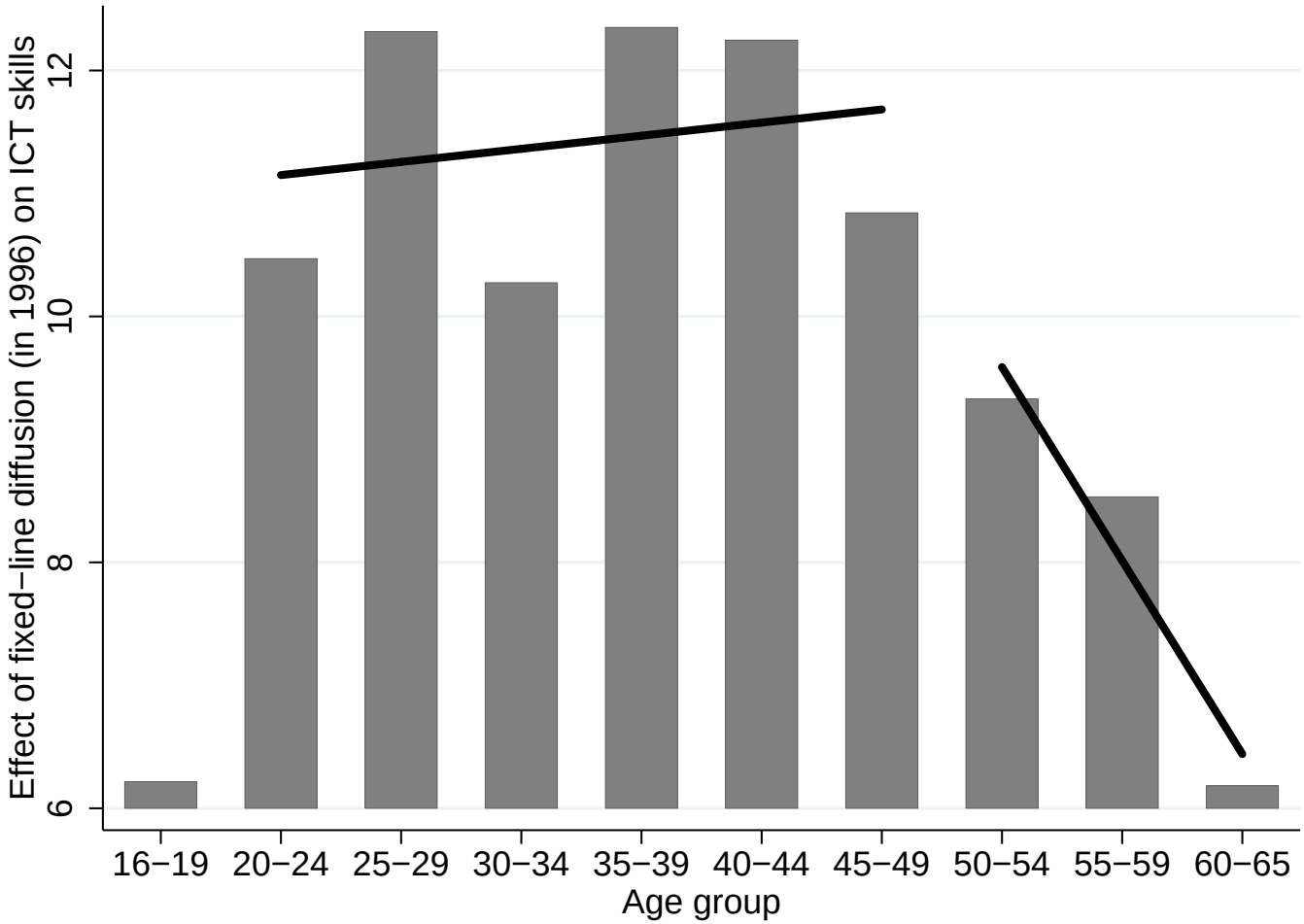
Past Fixed-Line Diffusion and ICT Skills by Age Group



Notes: Coefficient estimates on fixed-line diffusion (in 1996) for indicated 5-year age groups in a regression of ICT skills (standardized to std. dev. 1 across countries) on fixed-line diffusion and all control variables included in Column (3) of the IV table. Sample: employees, no first-generation migrants. Slopes of solid lines reflect average change in the effect of fixed-line diffusion on ICT skills by age groups (separately estimated for ages 20–49 and 50–65). *Data sources:* ITU, OECD, PIAAC.

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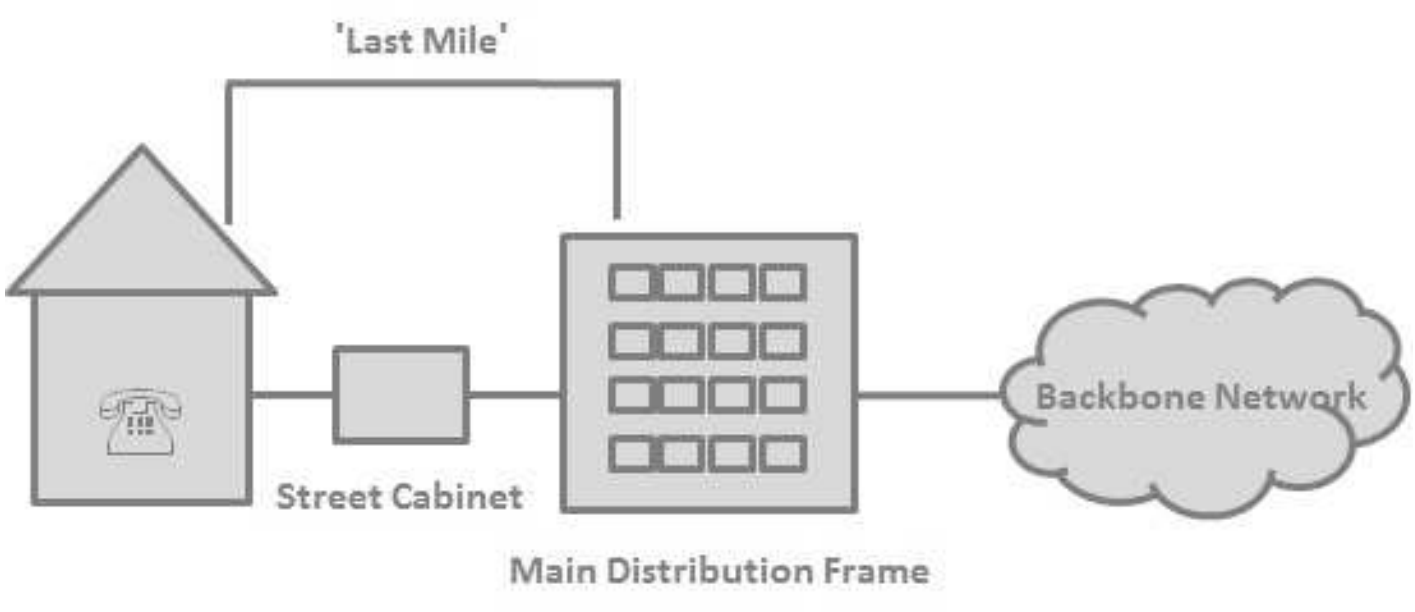
The Structure of a DSL Network



Notes: The figure shows the structure of a DSL network which relies on the "last mile" of the pre-existing voice-telephony network. The "last mile" consists of copper wires connecting every household via the street cabinet to the main distribution frame. At the main distribution frame a so-called DSLAM (Digital Subscriber Line Access Multiplexer) is installed that aggregates and redirects the voice and data traffic to the telco's backbone network.

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Descriptive Statistics: Individual-Level Variables

	Pooled	Australia	Austria	Belgium	Canada	Czech R.	Denmark	Estonia	Finland	Germany
Gross hourly wage	17.7	18.7	16.3	19.2	19.9	9.1	23.6	10.5	18.4	18.5
(in PPP-US-$)	(9.7)	(8.3)	(6.3)	(6.5)	(9.0)	(4.2)	(8.1)	(6.3)	(6.8)	(9.4)
ICT skills	294.0	297.3	291.4	291.0	293.5	287.2	296.5	282.2	304.3	295.4
	(39.8)	(36.5)	(36.1)	(40.2)	(41.3)	(43.9)	(37.5)	(41.0)	(37.9)	(39.6)
Yrs schooling	13.9	14.9	12.7	13.5	13.7	13.7	13.4	12.8	13.5	14.1
	(2.5)	(2.1)	(2.3)	(2.3)	(2.2)	(2.4)	(2.4)	(2.6)	(2.7)	(2.3)
Yrs experience	14.0	14.6	15.4	14.8	15.4	13.0	16.8	12.2	12.8	14.3
	(8.4)	(8.4)	(8.7)	(8.3)	(8.5)	(7.8)	(8.6)	(7.9)	(8.0)	(9.0)
Female	0.48	0.48	0.50	0.49	0.48	0.44	0.50	0.53	0.50	0.47
Children?	0.58	0.48	0.56	0.66	0.54	0.62	0.63	0.65	0.60	0.55
Observations	40,869	1,926	1,667	1,764	7,531	1,594	1,902	2,162	2,013	1,906

	Ireland	Japan	Korea	Netherl.	Norway	Poland	Slovak R.	Sweden	U.K.	U.S.
Gross hourly wage	22.2	15.3	17.0	19.9	24.6	9.4	9.0	18.2	18.9	21.1
(in PPP-US-$)	(11.3)	(9.2)	(13.4)	(8.6)	(8.4)	(5.5)	(6.0)	(5.3)	(11.4)	(12.7)
ICT skills	284.7	305.6	288.5	300.8	299.8	276.0	284.8	305.3	295.2	289.2
	(37.6)	(40.9)	(34.9)	(36.5)	(36.2)	(47.0)	(36.8)	(37.7)	(39.3)	(43.3)
Yrs schooling	16.2	13.8	14.3	14.0	14.8	14.5	14.2	12.8	13.3	14.2
	(2.3)	(2.3)	(2.3)	(2.2)	(2.2)	(2.6)	(2.5)	(2.2)	(2.3)	(2.5)
Yrs experience	14.0	13.5	9.8	14.6	14.6	10.4	12.8	13.7	15.7	15.5
	(8.0)	(7.8)	(6.9)	(8.0)	(8.1)	(7.7)	(8.3)	(8.7)	(8.8)	(8.6)
Female	0.56	0.41	0.44	0.49	0.49	0.47	0.48	0.49	0.48	0.52
Children?	0.51	0.49	0.53	0.52	0.65	0.57	0.58	0.59	0.57	0.61
Observations	1,451	1,677	1,934	1,854	1,980	2,365	1,357	1,595	2,818	1,373

Notes: Means, standard deviations (in parentheses), and numbers of observations for selected variables by country. Sample: employees aged 20–49, no first-generation migrants. Pooled specification gives same weight to each country. *Data source:* PIAAC.

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Descriptive Statistics: Country-Level Variables

	Pooled	Australia	Austria	Belgium	Canada	Czech R.	Denmark	Estonia	Finland	Germ.
Emergence broadband		1999	1999	2000	1999	2000	1999	2000	1999	1999
Fixed line diff. (1996)	0.49	0.50	0.48	0.46	0.61	0.27	0.62	0.31	0.55	0.54
GDP per capita (1996)	25.05	28.37	29.06	27.50	28.90	17.37	29.12	8.47	22.61	27.95
Rural population (1996)	0.24	0.14	0.34	0.03	0.22	0.25	0.15	0.30	0.19	0.27
Service sector	0.69	0.69	0.70	0.76	0.70	0.75	0.60	0.67	0.70	0.68
Union density	0.32	0.18	0.27	0.55	0.27	0.13	0.67	0.06	0.69	0.18
EPL	2.26	1.99	2.44	2.99	1.51	2.66	2.32	2.07	2.17	2.84
Public sector	0.29	0.25	0.26	0.29	0.33	0.26	0.39	0.30	0.36	0.15
Youth UR	0.16	0.12	0.09	0.20	0.14	0.19	0.14	0.20	0.18	0.08
Enrollment tertiary edu.	0.05	0.06	0.04	0.04	0.04	0.04	0.05	0.05	0.06	0.04
Cable diffusion (1996)	0.19	0.02	0.10	0.36	0.27	0.06	0.24	0.44	0.16	0.20

	Ireland	Japan	Korea	Netherl.	Norway	Poland	Slovak R.	Sweden	U.K.	U.S.
Emergence broadband	2000	1999	2000	1999	1999	2001	2000	1999	1999	1999
Fixed line diff. (1996)	0.38	0.51	0.43	0.54	0.57	0.17	0.23	0.68	0.53	0.62
GDP per capita (1996)	23.55	28.69	16.92	29.31	39.54	9.64	11.55	25.00	25.68	36.02
Rural population (1996)	0.42	0.22	0.21	0.26	0.26	0.38	0.44	0.16	0.22	0.22
Service sector	0.71	0.73	0.59	0.76	0.58	0.64	0.72	0.61	0.79	0.78
Union density	0.31	0.18	0.10	0.18	0.53	0.13	0.17	0.68	0.26	0.11
EPL	2.07	2.09	2.17	2.88	2.31	2.39	2.16	2.52	1.76	1.17
Public sector	0.32	0.13	0.16	0.29	0.38	0.22	0.28	0.39	0.34	0.23
Youth UR	0.33	0.08	0.09	0.09	0.09	0.26	0.34	0.24	0.21	0.16
Enrollment tertiary edu.	0.04	0.03	0.07	0.05	0.05	0.05	0.04	0.05	0.04	0.07
Cable diffusion (1996)	0.15	0.10	0.15	0.37	0.15	0.07	0.08	0.21	0.04	0.24

Notes: Emergence broadband: year in which predicted broadband penetration reaches 1 percent. *Fixed line diff. (1996):* voice telephony penetration rate (telephone access lines per inhabitant) in 1996. *Rural population (1996):* share of total population living in rural areas in 1996. *Service sector:* share of service sector in the GDP. *Union density:* share of wage and salary earners who are trade union members. *EPL:* composite indicator measuring strictness of employment protection legislation for individual and collective dismissals. *Public sector:* share of workers employed in the public sector. *Youth UR:* unemployment rate of persons aged 15–24. *Enrollment tertiary education:* share of population currently in tertiary education. *Cable diffusion (1996):* cable television subscribers per inhabitant in 1996. GDP per capita is expressed in PPP-US-$ (divided by 1000). *Data sources:* ITU, OECD, PIAAC, Statistics

Returns to ICT Skills (OLS)

Dependent variable: log gross hourly wage	(1)	(2)	(3)	(4)
ICT skills	0.096***	0.120***	0.073***	0.059***
	(0.009)	(0.008)	(0.009)	(0.007)
Experience		0.043***	0.037***	0.036***
		(0.003)	(0.003)	(0.003)
Experience^2 (/100)		–0.080***	–0.063***	–0.062***
		(0.007)	(0.007)	(0.006)
Female		–0.121***	–0.148***	–0.159***
		(0.018)	(0.018)	(0.019)
Years of schooling			0.057***	0.066***
			(0.005)	(0.004)
Country characteristics	X	X	X	
Country fixed effects				X
R squared (adjusted)	0.35	0.45	0.50	0.53
Individuals	40,869	40,869	40,869	40,869
Countries	19	19	19	19

Notes: Ordinary least squares estimation weighted by sampling weights (giving same weight to each country). Sample: employees aged 20–49, no first-generation migrants. ICT skills are standardized to std. dev. 1 across countries. Country characteristics are GDP per capita in 1996 measured in PPP-US-$ (in logs) and average wages of exit-age workers in 2011/12 (in logs). Robust standard errors, adjusted for clustering at the country level, in parentheses. Significance levels: * p<0.10, ** p<0.05, *** p<0.01. *Data sources:* ITU, OECD, PIAAC.

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IV Results: First Stage

Dependent variable: ICT skills	(1)	(2)	(3)
Fixed-line diffusion in 1996	6.308***	6.673***	11.652***
	(1.055)	(0.878)	(1.574)
Experience		–0.014	–0.073**
		(0.027)	(0.025)
Experience^2 (/100)		–0.328***	–0.095
		(0.080)	(0.073)
Female		–0.670***	–0.922***
		(0.134)	(0.104)
Years of schooling			0.676***
			(0.027)
Country characteristics	X	X	X
Instrument F statistic	35.7	57.8	54.8
Individuals	40,869	40,869	40,869
Countries	19	19	19

Notes: Table reports first-stage results of two-stage least squares estimations presented below. Robust standard errors, adjusted for clustering at the country level, in parentheses. Significance levels: * p<0.10, ** p<0.05, *** p<0.01. *Data sources:* ITU, OECD, PIAAC.

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IV Results: First Stage by Migration Status

Dependent variable: ICT skills	Natives	2nd-gen. migrants	1st-gen. migrants
Fixed-line diffusion in 1996	12.025***	9.757***	–1.360
	(1.699)	(1.342)	(1.498)
Experience	–0.072**	–0.066	–0.054
	(0.027)	(0.040)	(0.057)
Experience^2 (/100)	–0.112	0.003	0.056
	(0.077)	(0.123)	(0.150)
Female	–0.951***	–0.714***	–0.884***
	(0.104)	(0.172)	(0.201)
Years of schooling	0.671***	0.709***	0.690***
	(0.028)	(0.030)	(0.049)
Country characteristics	X	X	X
R squared (adjusted)	0.18	0.18	0.14
Individuals	36,667	4,014	4,842
Countries	19	19	19

Notes: Ordinary least squares estimation weighted by sampling weights (giving same weight to each country). Sample: employees aged 20–49. ICT skills are standardized to std. dev. 1 across countries, using the country-level std. dev. as "numeraire" scale. *Native:* participant and both parents born in the country of residence. *1st-gen. migrants:* participant born abroad; at least one parent as well. *2nd-gen. migrants:* mother, father, or both born abroad; participant born in country of residence. *Fixed-line diffusion in 1996:* voice telephony penetration rate (telephone access lines per inhabitant) in 1996. *GDP per capita in 1996 (log)* is measured in PPP-US-$ and obtained from the OECD. *Average wage level 50_60 (log)* is the mean wage (in purchasing power parities) of employees aged 50–60, without first-generation migrants, obtained from PIAAC. Fixed-line diffusion, GDP per capita, and average wages of exit-age workers are measured at the country level; all other variables are measured at the individual level. Robust standard errors, adjusted for clustering at the country level, in parentheses. Significance levels: * $p<0.10$, ** $p<0.05$, *** $p<0.01$. *Data sources:* ITU, OECD, PIAAC.

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IV Results: Second Stage

Dependent variable: log gross hourly wage	(1)	(2)	(3)
ICT skills	0.059**	0.053**	0.075***
	(0.026)	(0.023)	(0.012)
Experience		0.043***	0.042***
		(0.003)	(0.003)
Experience^2 (/100)		–0.071***	–0.057***
		(0.012)	(0.008)
Female		–0.101***	–0.094***
		(0.018)	(0.016)
Years of schooling			0.020**
			(0.009)
Country characteristics	X	X	X
First stage (Dependent variable: ICT skills)			
Fixed-line diffusion in 1996	6.183***	6.568***	11.601***
	(1.102)	(0.905)	(1.554)
Instrument F statistic	31.5	52.6	55.7
Individuals	40,869	40,869	40,869
Countries	19	19	19

Notes: Two-stage least squares estimation weighted by sampling weights (giving same weight to each country). Sample: employees aged 20–49, no first-generation migrants. Dependent variable in second stage, *log gross hourly wage*, is measured in purchasing power parities. ICT skills are standardized to std. dev. 1 across countries, using the country-level std. dev. as "numeraire" scale. *Fixed-line diffusion in 1996:* voice-telephony penetration rate (telephone access lines per inhabitant) in 1996. *GDP per capita in 1996 (log)* is measured in PPP-US-$ and obtained from the OECD. *Average wage level 50_60 (log)* is the mean wage (in purchasing power parities) of employees aged 50–60, without first-generation migrants, obtained from PIAAC. Fixed-line diffusion, GDP per capita, and average wages of exit-age workers are measured at the country level; all other variables are measured at the individual level. Robust standard errors, adjusted for clustering at the country level, in parentheses. Significance levels: * $p<0.10$, ** $p<0.05$, *** $p<0.01$. *Data sources:* ITU, OECD, PIAAC.

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Full Model

Third stage (Dependent variable: log gross hourly wage)	(1)	(2)	(3)
ICT skills	0.059**	0.053**	0.075***
	(0.027)	(0.024)	(0.012)
Country characteristics	X	X	X
Experience and gender		X	X
Years of schooling			X
Second stage (Dependent variable: ICT skills)			
Broadband diffusion in 2012	21.552*	22.884*	41.835**
	(12.085)	(12.444)	(19.276)
First stage (Dependent variable: Broadband diffusion in 2012)			
Fixed-line diffusion in 1996	0.287*	0.287*	0.277*
	(0.148)	(0.148)	(0.144)
Individuals	40,869	40,869	40,869
Countries	19	19	19

Notes: Three-equation seemingly unrelated regression estimation weighted by sampling weights (giving same weight to each country). Sample: employees aged 20–49, no first-generation migrants. Dependent variable in third stage, *log gross hourly wage*, is measured in purchasing power parities. ICT skills are standardized to std. dev. 1 across countries, using the country-level std. dev. as "numeraire" scale. *Broadband diffusion in 2012:* actual diffusion of broadband Internet (measured as the number of broadband subscribers per inhabitant). *Fixed-line diffusion in 1996:* voice-telephony penetration rate (telephone access lines per inhabitant) in 1996. Broadband diffusion, fixed-line diffusion, GDP per capita, and average wages of exit-age workers are measured at the country level; all remaining variables are measured at the individual level. Robust standard errors, adjusted for clustering at the country level, in parentheses. Significance levels: * $p<0.10$, ** $p<0.05$, *** $p<0.01$. *Data sources:* ITU, OECD, PIAAC.

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Placebo Test

Dependent variable: cognitive skills in	Numeracy (1)	Literacy (2)	ICT (3)	ICT (4)
Fixed-line diffusion in 1996	1.769	1.984	4.529***	3.697***
	(1.860)	(1.190)	(0.923)	(0.598)
ICT skills	0.568***	0.636***		
	(0.016)	(0.016)		
Numeracy skills			0.846***	
			(0.016)	
Literacy skills				0.844***
				(0.014)
Country characteristics	X	X	X	X
Individual characteristics	X	X	X	X
R squared (adjusted)	0.57	0.62	0.57	0.62
Individuals	40,869	40,869	40,869	40,869
Countries	19	19	19	19

Notes: Ordinary least squares estimation weighted by sampling weights (giving same weight to each country). Sample: employees aged 20–49, no first-generation migrants. Numeracy, literacy, and ICT skills are standardized to std. dev. 1 across countries, using the country-level std. dev. as "numeraire" scale. *Fixed-line diffusion in 1996:* voice-telephony penetration rate (telephone access lines per inhabitant) in 1996. Country characteristics include GDP per capita in 1996 (in logs) and average wages of exit-age workers in 2011/12 (in logs). Individual characteristics are quadratic polynomial in work experience, gender, and years of schooling. All variables except for fixed-line diffusion and country characteristics are measured at the individual level. Robust standard errors, adjusted for clustering at the country level, in parentheses. Significance levels: * $p<0.10$, ** $p<0.05$, *** $p<0.01$. *Data sources:* ITU, OECD, PIAAC.

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Robustness: Country Controls

Second stage (Dependent variable: log gross hourly wage)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
ICT skills	0.079***	0.055***	0.075***	0.049***	0.075***	0.071***	0.071***
	(0.011)	(0.012)	(0.010)	(0.011)	(0.010)	(0.012)	(0.011)
Service Share	–0.388						
	(0.352)						
Union density		0.227***					
		(0.076)					
Employment protection			0.010				
			(0.022)				
Public sector				0.776***			
				(0.206)			
Youth unemployment rate					0.306		
					(0.232)		
People in tertiary education						1.425	
						(2.519)	
Cable diffusion in 1996							0.074
							(0.125)
Country characteristics	X	X	X	X	X	X	X
Individual characteristics	X	X	X	X	X	X	X
Instrument F statistic	48.5	30.5	78.7	35.9	58.4	52.1	47.9
Individuals	40,869	40,869	40,869	40,869	40,869	40,869	40,869
Countries	19	19	19	19	19	19	19

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Robustness: Individual Controls and Additional FE

Second stage (Dependent variable: log gross hourly wage)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
ICT skills	0.069***	0.066***	0.074***	0.077***	0.073***	0.064***	0.073***
	(0.013)	(0.013)	(0.011)	(0.012)	(0.009)	(0.012)	(0.011)
Age	0.058***						
	(0.008)						
Age^2 (/100)	–0.050***						
	(0.011)						
Potential work experience		0.040***					
		(0.003)					
Potential work experience^2 (/100)		–0.055***					
		(0.009)					
Full-time			–0.016				
			(0.045)				
Parental education				–0.030***			
				(0.011)			
Health					0.024***		
					(0.008)		
Country characteristics	X	X	X	X	X	X	X
Individual characteristics	X	X	X	X	X	X	X
Occupation fixed effects						X	
Industry fixed effects							X
Instrument F statistic	41.9	41.9	53.8	45.7	54.5	64.3	52.7
Individuals	40,869	40,869	40,869	39,062	33,334	40,482	40,373
Countries	19	19	19	19	18	19	19

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Within-Country Evidence: Main Results

Second stage (Dependent variable: log gross hourly wage)	Full sample			No own MDF sample		
	(1)	(2)	(3)	(4)	(5)	(6)
ICT skills	0.203***	0.201***	0.140*	0.224**	0.237**	0.190*
	(0.075)	(0.066)	(0.084)	(0.095)	(0.095)	(0.113)
Municipality characteristics	X	X	X	X	X	X
Experience and gender		X	X		X	X
Years of schooling			X			X
First stage (Dependent variable: ICT skills)						
Threshold	–0.895***	–0.824***	–0.586***	–1.259***	–1.123***	–0.807**
	(0.268)	(0.258)	(0.222)	(0.322)	(0.335)	(0.321)
Instrument F statistic	11.2	10.2	6.9	15.3	11.3	6.3
Individuals	1,417	1,417	1,417	122	122	122
Municipalities	205	205	205	18	18	18

Notes: Instrumental-variable estimation weighted by sampling weights (giving same weight to each country). Sample: West German employees aged 20–49, no first-generation migrants. Columns (1)–(3) show results for all West German municipalities in the sample; Columns (4)–(6) restrict sample to West German municipalities without an own main distribution frame (MDF). ICT skills are measured at the individual level and are standardized to std. dev. 1, using the municipality-level std. dev. as "numeraire" scale. The instrument is a threshold dummy indicating whether a municipality is more than 4,200 meters away from its main distribution frame (MDF) (1=lower probability of DSL availability). Distance calculations are based on municipalities' geographic centroid. Estimation is implemented through Limited Information Maximum Likelihood (LIML), where the user-specified constant (alpha) is set to 1. Fuller's (1977) modification of the LIML estimator is used, which ensures that the estimator has finite moments. Municipality characteristics are unemployment rate (i.e., share of unemployed individuals in the working-age population aged 18 to 65), population share of individuals older than 65, and average municipality-level wage of workers aged 50-60 years (obtained from PIAAC). Individual characteristics are quadratic polynomial in work experience and gender. Robust standard errors, adjusted for clustering at the municipality level, in parentheses. Significance levels: * $p<0.10$, ** $p<0.05$, *** $p<0.01$. *Data sources:* German Broadband Atlas, German Federal Statistical Office, PIAAC.

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Within-Country Evidence: Full Model

	Full sample			No own MDF sample		
Third stage (Dependent variable: log gross hourly wage)	(1)	(2)	(3)	(4)	(5)	(6)
ICT skills	0.213***	0.211***	0.156	0.240**	0.256**	0.224
	(0.082)	(0.072)	(0.095)	(0.108)	(0.110)	(0.145)
Municipality characteristics	X	X	X	X	X	X
Experience and gender		X	X		X	X
Years of schooling			X			X
Second stage (Dependent variable: ICT skills)						
Broadband availability	15.547**	14.213**	10.323**	29.027*	25.306*	19.529
	(6.747)	(5.755)	(5.072)	(15.289)	(13.225)	(12.047)
First stage (Dependent variable: Broadband availability)						
Threshold	–0.058***	–0.058***	–0.057***	–0.043**	–0.044**	–0.041*
	(0.020)	(0.020)	(0.020)	(0.021)	(0.022)	(0.022)
Individuals	1,417	1,417	1,417	122	122	122
Municipalities	205	205	205	18	18	18

Notes: Three-equation seemingly unrelated regression estimation weighted by sampling weights. Sample: West German employees aged 20–49, no first-generation migrants. Columns (1)–(3) show results for all West German municipalities in the sample; Columns (4)–(6) restrict sample to West German municipalities without an own main distribution frame (MDF). ICT skills are measured at the individual level and are standardized to std. dev. 1, using the municipality-level std. dev. as "numeraire" scale. *Broadband availability:* share of households in a municipality for which broadband Internet is technologically available (measured in 2008). *Threshold:* indicates whether a municipality is more than 4,200 meters away from its MDF (1=lower probability of DSL availability), and zero otherwise. Municipality characteristics are unemployment rate (i.e., share of unemployed individuals in the working-age population aged 18 to 65), population share of individuals older than 65, and average municipality-level wage of workers aged 50-60 years (obtained from PIAAC). Individual characteristics are quadratic polynomial in work experience and gender. Robust standard errors, adjusted for clustering at municipality level, in parentheses. Significance levels: * $p<0.10$, ** $p<0.05$, *** $p<0.01$. *Data sources:* German Broadband Atlas, German Federal Statistical Office, PIAAC.

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Within-Country Evidence: Placebo Test

	Panel A: Full Sample			
Dependent variable: cognitive skills in	Numeracy	Literacy	ICT	ICT
Threshold	0.278**	0.049	–0.502***	–0.310*
	(0.123)	(0.165)	(0.142)	(0.167)
ICT skills	0.676***	0.709***		
	(0.023)	(0.022)		
Numeracy skills			0.709***	
			(0.020)	
Literacy skills				0.754***
				(0.020)
	Panel B: No own MDF Sample			
Dependent variable: cognitive skills in	Numeracy	Literacy	ICT	ICT
Threshold	0.209	0.164	–0.616***	–0.482***
	(0.149)	(0.149)	(0.211)	(0.139)
ICT skills	0.599***	0.706***		
	(0.060)	(0.067)		
Numeracy skills			0.696***	
			(0.065)	
Literacy skills				0.801***
				(0.066)

Notes: Ordinary least squares estimation weighted by sampling weights. Sample: West German employees aged 20–49, no first-generation migrants. Numeracy, literacy, and ICT skills are measured at the individual level and are standardized to std. dev. 1, using the municipality-level std. dev. as "numeraire" scale. *Threshold:* indicates whether a municipality is more than 4,200 meters away from its main distribution frame (MDF) (1=lower probability of DSL availability), and zero otherwise. All regressions control for municipality characteristics (unemployment rate, population share of individuals older than 65, and average municipality-level wage of workers aged 50-60 years), individual characteristics (quadratic polynomial in work experience and gender), and years of schooling. Robust standard errors, adjusted for clustering at the municipality level, in parentheses. Significance levels: * $p<0.10$, ** $p<0.05$, *** $p<0.01$. *Data sources:* German Broadband Atlas, German Federal Statistical Office, PIAAC.

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Returns to ICT Skills and Computer Use/Tasks at Work

Second stage (Dependent variable: log gross hourly wage)	(1)	(2)	(3)	(4)	(5)	(6)
ICT skills (individual level)	0.060***	0.065***	0.061***	0.062***	0.066***	0.061***
	(0.010)	(0.009)	(0.010)	(0.010)	(0.009)	(0.009)
× computer use	–0.012					
	(0.012)					
× abstract task intensity		–0.017**			–0.015**	
		(0.008)			(0.008)	
× routine task intensity			0.009		0.003	
			(0.010)		(0.009)	
× manual task intensity				0.008	0.002	
				(0.013)	(0.013)	
× Routine Task Index (RTI)						0.008
						(0.007)
Computer use	–0.042					
	(0.039)					
Occupation FE	X	X	X	X	X	X
Country characteristics	X	X	X	X	X	X
Individual characteristics	X	X	X	X	X	X
Instrument F statistic main effect	158.5	157.6	157.1	155.9	78.0	156.5
Instrument F statistic interaction	43.6	53.0	54.0	45.2	27.2/29.0/24.9	50.2
Individuals	40,674	40,442	40,442	40,442	40,442	40,442
Country-occupation cells	754	717	717	717	717	717

Table Notes

Returns to ICT Skills and Computer Use/Tasks at Work

Second stage (Dependent variable: log gross hourly wage)	(1)	(2)	(3)	(4)	(5)	(6)
ICT skills (individual level)	0.060***	0.065***	0.061***	0.062***	0.066***	0.061***
	(0.010)	(0.009)	(0.010)	(0.010)	(0.009)	(0.009)
× computer use	–0.012					
	(0.012)					
× abstract task intensity		–0.017**			–0.015**	
		(0.008)			(0.008)	
× routine task intensity			0.009		0.003	
			(0.010)		(0.009)	
× manual task intensity				0.008	0.002	
				(0.013)	(0.013)	
× Routine Task Index (RTI)						0.008
						(0.007)
Computer use	–0.042					
	(0.039)					

Notes: Two-stage least squares estimation weighted by sampling weights (giving same weight to each country). Sample: employees aged 20–49, no first-generation migrants. Dependent variable in second stage, *log gross hourly wage*, is measured in purchasing power parities. ICT skills are standardized to mean 0 and std. dev. 1 across countries, using the country-level std. dev. as "numeraire" scale. Instruments are *Fixed-line diffusion in 1996*, defined as voice-telephony penetration rate (telephone access lines per inhabitant) in 1996, interacted with computer use in Column (1), abstract task intensity in Column (2), routine task intensity in Column (3), manual task intensity in Column (4), all tasks simultaneously in Column (5), and Routine Task Index (RTI), defined as ln(routine) - ln(abstract) - ln(manual), in Column (6). Computer use intensity is based on questions indicating how often a person performs the following activities at work: create or read spreadsheets, use word-processing software, use programming language, and engage in computer-aided real-time discussions; answers are combined to a single index following the procedure described in Kling, Liebman, and Katz (2007) and then aggregated to the country-occupation (two-digit ISCO level) level. Task measures are taken from Goos, Manning, and Salomons (2014) and are defined at the two-digit ISCO level. All variables are de-meaned. *Instrument F statistic main* refers to instrumentation of ICT skills and *Instrument F statistic interaction* refers to instrumentation of ICT-skills interactions. All specifications include two-digit occupation fixed effects, as well as controls for country characteristics and for individual characteristics. Main effects occupational task intensities cannot be estimated because variables do not vary within occupations. Robust standard errors, adjusted for clustering at the country-occupation level, in parentheses. Significance levels: * $p<0.10$, ** $p<0.05$, *** $p<0.01$. *Data sources:* Goos, Manning, and Salomons (2014), ITU, OECD, PIAAC.

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