Appendix for "Has ICT Polarized Skill Demand? Evidence from Eleven Countries over 25 years"

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A. Theory Appendix: A simple model of the effect of ICT on demand for three skill groups.

We present a simple model that illustrates how we could derive the relationships we observe in the data. The exogenous variable is an increase in ICT capital generated by a large fall in ICT prices. The prediction is that we can observe an increase in the share of the high-skilled and a decline in the share of the middle-skilled. Note that an increase in the supply of the middle-skilled will also generate an increase in their wage bill share.

The model below considers an aggregate (sectoral) production function using three labor inputs: low-skilled (L), middle-skilled (M), and high-skilled (H) workers and ICT capital (C). The model also assumes a constant elasticity of substitution $\sigma = \frac{1}{1-\rho} > 1$ between the three types of (ICT-augmented) labor inputs, so $\rho \in (0, 1)$. We assume that output, Q, is produced using the following production function:

$$Q = \left[\alpha_L L^{\rho} + (\alpha_M M + \beta C)^{\rho} + (\alpha_H H^{\mu} + \gamma C^{\mu})^{\rho/\mu}\right]^{\frac{1}{\rho}},$$

where α_j denotes the effectiveness of each type of labor, $j \in \{L, M, H\}$. β measures the effectiveness of ICT in substituting middle-skilled labor and γ measures ICT effectiveness in complementing high-skilled labor. The model assumes that ICT capital (C) is a substitute for middle-skilled workers, and a complement to

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high-skilled labor, where $\eta = \frac{1}{1-\mu} \in (0,1)$, so $\mu < 0$. Note that the model only treats the relationship between C and H in exactly the opposite way from the relationship between C and M if $\eta \longrightarrow 0$ (or equivalently $\mu \longrightarrow -\infty$).

Assuming perfect competition, the wage of the three types of labor and the cost of ICT are:

$$
\begin{aligned}
w_H &= \left[\alpha_L L^\rho + (\alpha_M M + \beta C)^\rho + (\alpha_H H^\mu + \gamma C^\mu)^{\rho/\mu}\right]^{\frac{1}{\rho}-1} (\alpha_H H^\mu + \gamma C^\mu)^{(\rho/\mu)-1} \alpha_H H^{\mu-1} \\
w_M &= \left[\alpha_L L^\rho + (\alpha_M M + \beta C)^\rho + (\alpha_H H^\mu + \gamma C^\mu)^{\rho/\mu}\right]^{\frac{1}{\rho}-1} (\alpha_M M + \beta C)^{\rho-1} \alpha_M \\
w_L &= \left[\alpha_L L^\rho + (\alpha_M M + \beta C)^\rho + (\alpha_H H^\mu + \gamma C^\mu)^{\rho/\mu}\right]^{\frac{1}{\rho}-1} \alpha_L L^{\rho-1} \\
p &= \left[\alpha_L L^\rho + (\alpha_M M + \beta C)^\rho + (\alpha_H H^\mu + \gamma C^\mu)^{\rho/\mu}\right]^{\frac{1}{\rho}-1} \\
&\quad * \left[(\alpha_M M + \beta C)^{\rho-1} \beta + (\alpha_H H^\mu + \gamma C^\mu)^{(\rho/\mu)-1} \gamma C^{\mu-1}\right] \\
&= \frac{\beta}{\alpha_M} w_M + \frac{\gamma C^{\mu-1}}{\alpha_H H^{\mu-1}} w_H
\end{aligned}
$$

In this model an increase in ICT raises the wage of high-skilled and low-skilled workers, but has an ambiguous effect on the wage of middle-skilled workers:

$$\frac{\partial w_H}{\partial C} > 0, \frac{\partial w_L}{\partial C} > 0.$$

The wage bill shares of the three types of labor are:

$$
\begin{aligned}
\theta_H &= \frac{w_H H}{w_L L + w_M M + w_H H} = \\
&= \frac{\left(\alpha_H H^\mu + \gamma C^\mu\right)^{(\rho/\mu)-1} \alpha_H H^\mu}{\alpha_L L^\rho + \alpha_M \left(\alpha_M M^{\frac{-\rho}{1-\rho}} + \beta C M^{\frac{-1}{1-\rho}}\right)^{\rho-1} + \left(\alpha_H H^\mu + \gamma C^\mu\right)^{(\rho/\mu)-1} \alpha_H H^\mu} \\
\theta_M &= \frac{w_M M}{w_L L + w_M M + w_H H} = \\
&= \frac{\alpha_M \left(\alpha_M M^{\frac{-\rho}{1-\rho}} + \beta C M^{\frac{-1}{1-\rho}}\right)^{\rho-1}}{\alpha_L L^\rho + \alpha_M \left(\alpha_M M^{\frac{-\rho}{1-\rho}} + \beta C M^{\frac{-1}{1-\rho}}\right)^{\rho-1} + \left(\alpha_H H^\mu + \gamma C^\mu\right)^{(\rho/\mu)-1} \alpha_H H^\mu} \\
\theta_L &= \frac{w_L L}{w_L L + w_M M + w_H H} = \\
&= \frac{\alpha_L L^\rho}{\alpha_L L^\rho + \alpha_M \left(\alpha_M M^{\frac{-\rho}{1-\rho}} + \beta C M^{\frac{-1}{1-\rho}}\right)^{\rho-1} + \left(\alpha_H H^\mu + \gamma C^\mu\right)^{(\rho/\mu)-1} \alpha_H H^\mu}
\end{aligned}
$$

One can verify that in this specification:

$$
\frac{\partial \theta_H}{\partial C} > 0, \frac{\partial \theta_M}{\partial C} < 0,
$$

so increased supply of ICT raises the college wage bill share and reduces the middle-skilled wage bill share. The ratio of the wage bill of high (middle) skilled workers to low-skilled workers increases (decreases) with ICT:

$$
\begin{aligned}
\frac{\partial}{\partial C}\left(\frac{w_H H}{w_L L}\right) &= \frac{\partial}{\partial C}\left[\frac{\left(\alpha_H H^\mu + \gamma C^\mu\right)^{(\rho/\mu)-1} \alpha_H H^\mu}{\alpha_L L^\rho}\right] > 0 \\
\frac{\partial}{\partial C}\left(\frac{w_M M}{w_L L}\right) &= \frac{\partial}{\partial C}\left[\frac{\alpha_M \left(\alpha_M M^{\frac{-\rho}{1-\rho}} + \beta C M^{\frac{-1}{1-\rho}}\right)^{\rho-1}}{\alpha_L L^\rho}\right] < 0
\end{aligned}
$$

Note that an increase in the supply of middle-skilled workers raises their wage bill relative to low-skilled workers:

$$
\frac{\partial}{\partial M}\left(\frac{w_M M}{w_L L}\right) = \frac{\partial}{\partial M}\left[\frac{\alpha_M \left(\alpha_M M^{\frac{-\rho}{1-\rho}} + \beta C M^{\frac{-1}{1-\rho}}\right)^{\rho-1}}{\alpha_L L^\rho}\right] > 0
$$

B. Data Appendix

Our main dataset is EUKLEMS (http://www.euklems.net/), which is an industry-level panel dataset created by economic researchers funded by the European Commission. It covers the European Union, the US, Japan, and other countries, and contains a wealth of information on productivity-related variables. These were constructed through joint work with census bureau in each country and are designed to be internationally comparable. Details of the methodology are in Timmer et al (2007).

In the construction of our sample we faced a number of technical issues. First, although college wage bill shares are reported for 30 industries in each country, these reported wage bill shares are not unique within each country. For example, in a certain country the reported college wage bill share for industry A and industry B may be (college wage bill in A + college wage bill in B)/(total wage bill in A + total wage bill in B). The identity and number of industries pooled together vary across countries. In order to use as much of variation as possible, we aggregate industries within each country up to the lowest level of aggregation that ensures that the college wage bill share is unique across the aggregated observations. This is also sufficient to ensure that other variables we use, such as our ICT and value added measures, have unique values across observations.

Second, as a measure of ICT intensity we use ICT capital compensation divided by value added directly from EUKLEMs. ICT capital is built using the Perpetual Inventory method based on real ICT investment flows (using a quality-adjusted price deflator). ICT capital compensation is the stock of ICT capital multiplied by its user cost. Non-ICT capital compensation is built in the same way[27].

Third, matching trade variables into our main dataset required data required currency conversions, since EUKLEMS reports data in historical local currency and COMTRADE reports data in historical dollars. To overcome this difference, we convert nominal values to current US Dollars using exchange rates from the IMF IFS website. To convert national currency to the Euro (for Eurozone countries), we use exchange rates from the website:

http://ec.europa.eu/economy_finance/euro/transition/conversion_rates.htm

[27] Because EUKLEMS calculates capital compensation as a residual in a few cases observations can have negative capital compensation. Of the 208 country-industry cells we use, negative capital compensation occurs in 12 cases in 1980 and in 3 cases in 2004. These are typically agriculture (which is heavily subsidized and becomes smaller over time) and industries where public services play an important role (e.g. education and health). To overcome this problem, we bottom-coded negative values of ICT and non-ICT capital compensation to zero. Our results are robust to dropping these observations from the sample.

We use trade figures from the UN's COMTRADE dataset. Data is downloaded in the four digit Standard International Trade Classification format (revision 2), and converted to the European NACE Rev 1 classification used in the EUKLEMS dataset (concordance available on request). Our trade regressions contain the updated data from 21st March 2008.

To decompose trade into OECD versus non-OECD, we use the 2007 definition of OECD countries (Austria, Australia, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, the Slovak Republic, Spain, Sweden, Switzerland, Turkey, the UK and the USA). This means that Czechoslovakia and Belgium-Luxembourg were treated as OECD countries in 1980.

Finally, we account for the fact that the (aggregated) industries we use differ substantially in their employment shares within each country's population. We therefore use the employment shares of each industry in 1980 (our base year) in total employment as analytical weights in the regressions using both tradable and non-tradable industries. For trade regressions, which use only the traded industries, each industry's weight is its employment share in the traded industries for that country, so that the sum of weights for each country is still equal to one.

Appendix Table A1: List of all EUKLEMS Industries:

Manufacturing		Services	
Code	**Code Description**	**Code**	**Code Description**
AtB	Agriculture, hunting, forestry and fishing	50	Sale, maintenance and repair of motor vehicles and motorcycles; retail sale of fuel
C	Mining and quarrying	51	Wholesale trade and commission trade, except of motor vehicles and motorcycles
15t16	Food products, beverages and tobacco	52	Retail trade, except of motor vehicles and motorcycles; repair of household goods
17t19	Textiles, textile products, leather and footwear	60t63	Transport and storage
20	Wood and products of wood and cork	64	Post and telecommunications
21t22	Pulp, paper, paper products, printing and publishing	70	Real estate activities
23	Coke, refined petroleum products and nuclear fuel	71t74	Renting of machinery and equipment and other business activities
24	Chemicals and chemical products	E	Electricity, gas and water supply
25	Rubber and plastics products	F	Construction
26	Other non-metallic mineral products	H	Hotels and restaurants
27t28	Basic metals and fabricated metal products	J	Financial intermediation
29	Machinery, not elsewhere classified	L	Public administration, defence, and compulsory social security
30t33	Electrical and optical equipment	M	Education
34t35	Transport equipment	N	Health and social work
36t37	Manufacturing not elsewhere classified; recycling	O	Other community, social and personal services

Appendix Table A2: List of Industries Pooled by Country

	NACE codes
Austria	15t16 plus 17t19 plus 36t37; 20 plus 21t22 plus 24 plus 25 plus 26 plus 27t28; 29 plus 30t33 plus 34t35; 50 plus 51 plus 52 plus H; 60t63; 64; 70 plus 71t74; AtB; F; J; L; M; N; O
Denmark	15t16; 17t19; 36t37; 20; 21t22; 24; 25; 26; 27t28; 29; 30t33; 34t35; 50; 51; 52; H; 60t63; 64; 70; 71t74; AtB; F; J; L; M; N; O
Finland	15t16 plus 17t19 plus 36t37; 20 plus 21t22 plus 24 plus 25 plus 26 plus 27t28; 29 plus 30t33 plus 34t35; 50 plus 51 plus 52 plus H; 60t63; 64; 70 plus 71t74; AtB; F; J; L; M; N; O
France	15t16 plus 17t19 plus 36t37; 20 plus 21t22 plus 24 plus 25 plus 26 plus 27t28; 29 plus 30t33 plus 34t35; 50 plus 51 plus 52 plus H; 60t63; 64; 70 plus 71t74; AtB; F; J; L; M; N; O
Germany	15t16 plus 17t19; 20 plus 21t22 plus 24 plus 25 plus 26 plus 27t28 plus 29; 30t33 plus 34t35; 36t37; 50 plus 51 plus 52 plus H; 60t63 plus 64; 70 plus 71t74; AtB; F; J; L; M; N; O
Italy	15t16; 17t19; 20; 21t22;24; 25; 26; 27t28; 29; 30t33; 34t35; 36t37; 50; 51; 52; H; 60t63; 64; 70; 71t74; AtB; F; J; L; M; N; O
Japan	AtB; 20; 60t63; 64; H; 17t19; 26; 27t28; 50; 25 plus 36t37; 34t35; 15t16; O; 29; 52; 30t33; F; 21t22; 24; 71t74; 51; J; 70; L plus M plus N
Netherlands	AtB; F; 50 plus 51 plus 52 plus H; 64; 15t16 plus 17t19; 60t63; 20 plus 21t22 plus 24 plus 25 plus 26 plus 27t28 plus 36t37; J; 29 plus 30t33 plus 34t35; L; N; 70 plus 71t74; M; O
Spain	15t16; 17t19; 20 plus 21t22 plus 24 plus 25 plus 26 plus 27t28; 29; 30t33; 34t35; 36t37; 50 plus 51 plus 52; 60t63; 64; 70 plus 71t74; AtB; F; H; J; L; M; N; O
UK	64; F; 50 plus 51 plus 52 plus H; 15t16 plus 17t19 plus 36t37; AtB; 60t63; 20 plus 21t22 plus 24 plus 25 plus 26 plus 27t28; 29 plus 30t33 plus 34t35; O; L; J; N; 70 plus 71t74; M
USA	15t16; 17t19; 36t37; 20; 21t22; 24; 25; 26; 27t28; 29; 30t33; 34t35; 50; 51; 52; H; 60t63; 64; 70; 71t74; AtB; F; J; L; M; N; O

Appendix Table A3: Trade, ICT, and Research and Development

	Dependent variable: High-Skilled Wage Bill Share																	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
Δ ((Imports+ Exports) / (Value Added))	0.59	0.11																
	(0.15)	(0.25)																
Δ ((Imports) / (Value Added))			1.07	0.21														
			(0.30)	(0.45)														
Δ ((Exports) / (Value Added))					1.16	0.21												
					(0.30)	(0.54)												
Δ ((Imports OECD+ Exports OECD) / (Value Added))							0.68	-0.05										
							(0.18)	(0.37)										
Δ ((Imports OECD) / (Value Added))									1.44	-0.43								
									(0.52)	(0.91)								
Δ ((Exports OECD) / (Value Added))											1.10	0.03						
											(0.30)	(0.61)						
Δ ((Imports+Exports nonOECD) / (Value Added))													2.21	1.38				
													(0.58)	(0.73)				
Δ ((Imports nonOECD) / (Value Added))															2.09	1.14		
															(0.63)	(0.83)		
Δ ((Exports nonOECD) / (Value Added))																	10.97	9.30
																	(3.38)	(3.41)
Δ ((ICT capital) / (Value Added))	107.61	73.59	107.29	73.22	110.10	74.17	109.81	76.19	110.39	78.75	112.20	75.32	110.43	69.95	113.76	71.89	116.71	67.65
	(31.70)	(31.41)	(31.52)	(31.32)	(32.04)	(31.41)	(31.94)	(31.57)	(31.55)	(31.40)	(32.51)	(31.53)	(31.13)	(30.44)	(32.06)	(30.75)	(29.66)	(29.74)
Δ ln(Value Added)	4.09	2.57	4.30	2.62	3.80	2.50	3.94	2.28	4.09	2.01	3.74	2.38	4.27	3.07	4.16	2.86	3.76	3.04
	(1.09)	(1.52)	(1.13)	(1.52)	(1.06)	(1.49)	(1.09)	(1.50)	(1.11)	(1.41)	(1.07)	(1.48)	(1.12)	(1.46)	(1.16)	(1.50)	(0.97)	(1.18)
Δ ((Non ICT capital) / (Value Added))	-0.63	0.97	-0.50	0.99	-0.76	0.95	-0.46	1.04	0.00	0.90	-0.82	1.01	-1.10	0.61	-1.20	0.47	0.24	2.77
	(2.41)	(3.12)	(2.38)	(3.11)	(2.45)	(3.13)	(2.39)	(3.05)	(2.33)	(2.98)	(2.46)	(3.13)	(2.50)	(3.22)	(2.51)	(3.24)	(2.42)	(2.97)
1980 (Research and Development Expenditure/ Value Added)		28.04		28.05		28.27		30.89		32.97		29.83		25.38		26.73		25.85
		(17.59)		(16.88)		(18.06)		(18.27)		(17.36)		(18.33)		(15.53)		(15.88)		(13.84)
Country fixed effects	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Obs.	84	65	84	65	84	65	84	65	84	65	84	65	84	65	84	65	84	65
R-squared	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.83	0.82	0.82	0.83	0.83

Note: *Coefficients estimated by OLS with robust standard errors in parentheses. Regressions weighted by the industry's 1980 share of each country's employment, for traded goods. The OECD ANBERD dataset does not have R&D data for Austria and Spain, which are dropped from the sample (columns 2,4,6,8,10,12,14,16 and 18).*

Appendix Table A4: Contribution of Changes in ICT and R&D to Changes in the High-Skilled Wage Bill Share

	(1)	(2)	(3)	(4)	(5)	(6)
Sectors	**All**	**All**	**Traded**	**Traded**	**All**	**All**
Method	No Controls, OLS	Full Controls, OLS	No Controls, OLS	Full Controls, OLS	No controls, IV	Full controls, IV
Δ (High-skilled wage-bill share)	10.02	10.02	9.37	9.37	10.02	10.02
Δ ((ICT capital) / (Value Added))	0.018	0.018	0.017	0.017	0.018	0.018
Coefficient on ICT	72.3	46.9	83.1	75.5	152.3	121.6
Mean*Coefficient of ICT	1.32	0.86	1.45	1.31	2.78	2.22
Mean contribution % of ICT	13.16	8.50	15.43	14.03	27.72	22.14
Table and columns used	Table 3 column (2)	Table 3 column (4)	Table 6 column (7)			Table 4 column (6)
Research and Development/Value Added			0.028	0.028		
Coefficient on R&D			52.79	30.08		
Mean*Coefficient on R&D			1.49	0.85		
Mean contribution of R&D			15.90	9.06		

Note: *This table contains a "back of the envelope" calculation of the contribution of technology to accounting for the changes in the high-skilled wage bill share.*