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ABSTRACT

OECD labor markets have become more "polarized" with employment in the middle of the skill distribution falling relative to the top and (in recent years) also the bottom of the skill distribution. We test the hypothesis of Autor, Levy, and Murnane (2003) that this is partly due to information and communication technologies (ICT) complementing the analytical tasks primarily performed by highly educated workers and substituting for routine tasks generally performed by middle educated workers (with little effect on low educated workers performing manual non-routine tasks). Using industry level data on the US, Japan, and nine European countries 1980-2004 we find evidence consistent with ICT-based polarization. Industries with faster growth of ICT had greater increases in relative demand for high educated workers and bigger falls in relative demand for middle educated workers. Trade openness is also associated with polarization, but this is not robust to controls for technology (like R&D). Technologies can account for up to a quarter of the growth in demand for the college educated in the quarter century since 1980.

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1. Introduction

The demand for more highly educated workers appears to have risen for many decades across OECD countries. Despite a large increase in the supply of such workers, the return to college education has not fallen. Instead, it has risen significantly since the early 1980s in the US, UK, and many other nations (see Machin and Van Reenen, 2008). The consensus view is that this increase in skill demand is linked to technological progress (e.g. Goldin and Katz, 2008) rather than increased trade with low wage countries (although see Krugman, 2008, for a more revisionist view).

Recent analyses of data through the 2000s, however, suggest a more nuanced view of the change in demand for skills. Autor, Katz, and Kearney (2007, 2008) use US data to show that although "upper tail" inequality (between the 90th and 50th percentiles of the wage distribution) has continued to rise in an almost secular way over the last thirty years, "lower tail" inequality (between the 50th and 10th percentiles of the distribution) increased during the 1980s but has stayed relatively flat from around 1990. They also show a related pattern for different education groups, with the hourly wages of college graduates' rising relative to high school graduates since 1980, and high school graduates gaining relative to high school dropouts during the 1980s but not since then. When considering occupations, rather than education groups, Goos and Manning (2007) describe a polarization of the workforce. In the UK middle skilled occupations have declined relative to both the highly skilled and low skilled occupations. Spietz-Oener (2006) finds related results for Germany and Goos, Manning and Salomons (2009) find similar results for several OECD countries[1].

What could account for these trends? One explanation is that new technolo-

[1] See also Dustmann, Ludsteck and Schonberg (2009) and Smith (2008).

gies, such as information and communication technologies (ICT), are complementary with human capital and rapid falls in quality-adjusted ICT prices have therefore increased skill demand. There is a large body of literature broadly consistent with this notion[2]. A more sophisticated view has been offered by Autor, Levy and Murnane (2003) who emphasize that ICT substitutes for *routine* tasks but complements *non-routine* analytical tasks. Many routine tasks were traditionally performed by less educated workers, such as assembly workers in a car factory, and many of the analytical non-routine tasks are performed by more educated workers such as consultants, advertising executives and physicians. However, many routine tasks are also performed in occupations employing middle educated workers, such as bank clerks, and these groups may find demand for their services falling as a result of computerization. Similarly many less educated workers are employed in non-routine manual tasks such as janitors or cab drivers, and these tasks are much less affected by ICT. Since the numbers of routine jobs in the traditional manufacturing sectors (like car assembly) declined substantially in the 1970s, subsequent ICT growth may have primarily increased demand for highly educated workers at the expense of those in the *middle* of the educational distribution and left the least educated (mainly working in non-routine manual jobs) largely unaffected.

Although this theory is attractive there is currently little direct international evidence that ICT causes a substitution from middle-skilled workers to high-skilled workers. Autor, Levy and Murnane (2003) show some consistent trends for the US and Autor and Dorn (2009) exploit spatial variation across the US to show that the growth in low skilled services has been faster in areas where initially there were high proportions of routine jobs.[3]

[2] See Bond and Van Reenen (2007) for a survey. Industry level data are used by Berman, Bound and Griliches (1994), Autor, Katz and Krueger (1998) and Machin and Van Reenen (1998). Krueger (1993), DiNardo and Pischke (1997) and Lang (2002) use individual data.

[3] The closest antecedent of our paper is perhaps Autor, Katz and Krueger (1998, Table V) who found that in the US the industry level growth of demand for US high school graduates

In this paper we test the hypothesis that ICT may be behind the polarization of the labor market by implementing a simple test using 25 years of international cross-industry data. If the ICT-based explanation for polarization is correct, then we would expect that industries and countries that had a faster growth in ICT also experienced an increase in demand for college educated workers, relative to workers with intermediate levels of education. In this paper we show that this is indeed a robust feature of the international data.

We exploit the new EUKLEMS database, which provides data on college graduates and disaggregates non-college workers into two groups: those with low education and those with "middle level" education. For example, in the US the middle education group includes those with some college and high school graduates, but excludes high school drop-outs and GEDs (see Timmer et al, 2007, Table 5.3 for the country specific breakdown). The EUKLEMS database covers eleven developed economies (US, Japan, and nine countries in Western Europe) from 1980-2004 and also contains data on ICT capital. In analyzing the data we consider not only the potential role of ICT, but also several alternative explanations. In particular, we examine whether the role of trade in changing skill demand could have become more important in recent years (most of the early studies pre-dated the growth of China and India as major players).

The idea behind our empirical strategy is that the rapid fall in quality-adjusted ICT prices will have a greater effect in some country-industry pairs that are more reliant on ICT. This is because some industries are for technological reasons inherently more reliant on ICT than others. We have no compelling natural experiment, however, so our results should be seen as conditional correlations. We do, how-

between 1993 and 1979 was negatively correlated with the growth of computer use between 1993 and 1984. We find this is a robust feature of 11 OECD countries over a much longer time period. For other related work see Black and Spitz-Oener (2010), Firpo, Fortin and Lemieux (2009), and work surveyed by Acemoglu and Autor (2010).

ever, implement some instrumental variable strategies using the industry-specific base year levels of US ICT intensity and/or routine tasks as an instrument for subsequent ICT increases in other countries. These support the OLS results.

We conclude that technology - both ICT and Research and Development (R&D) - has raised relative demand for college educated workers and, consistent with the ICT-based polarization hypothesis, this increase has come mainly from reducing the relative demand for middle skilled workers rather than low skilled workers.

The paper is laid out as follows. Section II describes the empirical model, Section III the data and Section IV the empirical results. Section V offers some concluding comments.

2. Empirical Model

Consider the short-run variable cost function, $CV(.)$:

$$CV(W^H, W^M, W^L; C, K, Q) \tag{2.1}$$

where W indicates hourly wages and superscripts denote education/skill group S (H = highly educated workers, M = middle educated workers and L = low educated workers), K = non-ICT capital services, C = ICT capital services and Q = value added. If we assume that the capital stocks are quasi-fixed, factor prices are exogenous and that the cost function can be approximated by a second order flexible functional form such as translog then cost minimization (using Shephard's Lemma) implies the following three skill share equations:

$$SHARE^H = \phi_{HH} \ln(W^H/W^L) + \phi_{MH} \ln(W^M/W^L) + \alpha_{CH} \ln(C/Q) + \alpha_{KH} \ln(K/Q) + \alpha_{QH} \ln Q \tag{2.2}$$

$$SHARE^M = \phi_{HM}\ln(W^H/W^L)+\phi_{MM}\ln(W^M/W^L)+\alpha_{CM}\ln(C/Q)+\alpha_{KM}\ln(K/Q)+\alpha_{QM}\ln Q \tag{2.3}$$

$$SHARE^L = \phi_{HL}\ln(W^H/W^L)+\phi_{ML}\ln(W^M/W^L)+\alpha_{CL}\ln(C/Q)+\alpha_{CL}\ln(K/Q)+\alpha_{CM}\ln Q, \tag{2.4}$$

where $SHARE^S = \frac{W^S N^S}{W^H N^H + W^S N^M + W^L N^L}$ is the wage bill share of skill group $S = \{H, M, L\}$ and N^S is the number of hours worked by skill group S. Our hypothesis of the ICT-based polarization theory is that $\alpha_H > 0$ and $\alpha_M < 0$ [4].

Our empirical specifications are based on these equations. We assume that labor markets are national in scope and include country by time effects to capture relative wages (ϕ_{jt}). We also assume that there is unobserved heterogeneity between industry by country pairs (η_{ij}) and include fixed effects to account for these, giving the following three equations:

$$SHARE^S = \phi_{jt} + \eta_{ij} + \alpha_{CS}\ln(C/Q)_{ijt} + \alpha_{KS}\ln(K/Q)_{ijt} + \alpha_{QS}\ln Q_{ijt}, \tag{2.5}$$

where i = industry, j =country and t = year. We estimate in long (25 year) differences, Δ,to look at the historical trends and smooth out measurement error. We substitute levels rather than logarithms (i.e. $\Delta(C/Q)$ instead of $\Delta\ln(C/Q)$) because of the very large changes in ICT intensity over this time period. Some industry by country pairs had close to zero IT intensity in 1980 so their change is astronomical in logarithmic terms[5]. Consequently our three key estimating equations are:

[4] The exact correspondence between the coefficients on the capital inputs and the Hicks-Allen elasticity of complementarity is more complex (see Brown and Christensen, 1981).

[5] The range of $\Delta\ln(C/Q)$ lies between -1 and 23.5. We report some robustness checks using $\frac{\Delta(C/Q)}{C/Q}$ as an approximation.

$$\Delta SHARE_{ijt}^S = c_j^S + \beta_1^S \Delta(C/Q)_{ijt} + \beta_2^S \Delta(K/Q)_{ijt} + \beta_3^S \Delta \ln Q_{ijt} + u_{ijt}^S. \quad (2.6)$$

In the robustness tests we also consider augmenting equation (2.6) in various ways. Since ICT is only one aspect of technical change we also consider using Research and Development expenditures. Additionally, we consider trade variables (such as imports plus exports over value added) to test whether industries that were exposed to more trade upgraded the skills of their workforce at a more rapid rate than those who did not. This is a pragmatic empirical approach to examining trade effects. Under a strict Heckscher-Ohlin approach trade is a general equilibrium effect increasing wage inequality throughout the economy so looking at the variation by industry would be uninformative. However, since trade costs have declined more rapidly in some sectors than others (e.g. due to trade liberalization) we would expect the actual flows of trade to proxy this change and there to be a larger effect on workers in these sectors than in others who were less affected (Krugman, 2008, makes this argument).

Appendix A considers a theoretical model with parameter restrictions over equation (2.1) that implies that ICT is a substitute for middle skilled labor and a complement with highly skilled labor. Comparative static results from the model suggest that as ICT increases (caused by a fall in the quality-adjusted price of ICT) the wage bill share of skilled workers rises and the share of middle skilled workers falls. It also shows that all else equal an exogenous increase in the supply of middle skilled workers will cause their wage bill share to rise. Thus, although ICT could reduce the demand for the middle skilled group their share could still rise because of the long-run increase in supply.

3. Data

3.1. Data Construction

The main source of data for this paper is the EUKLEMS dataset, which contains data on value added, labor, capital, skills and ICT for various industries in many developed countries (see Timmer et al, 2007). The EUKLEMS data are constructed using data from each country's National Statistical Office (e.g. the US Census Bureau) and harmonized with each country's national accounts. EUKLEMS contains some data on most OECD countries. But since we require data on skill composition, investment and value added between 1980 and 2004, our sample of countries is restricted to eleven: Austria, Denmark, Finland, France, Germany, Italy, Japan, the Netherlands, Spain, the UK and the USA[6].

Another choice we had to make regards the set of industries we analyze. Since our baseline year (1980) was close to the peak of the oil boom, we have dropped energy-related sectors - mining and quarrying, coke manufactures and the supply of natural gas - from the sample (we report results that are very robust to the inclusion of these sectors). The remaining sample includes 27 industries in each country (see Appendix Table A1). But wage data by skill category are only reported separately by industry in some countries. We therefore aggregate industries to the lowest possible level of aggregation for which all the variables we use could be constructed – the precise level of disaggregation varied by country (see Appendix Table A2)[7]. Our final sample has 208 observations on country-industry cells for each of the years between 1980 and 2004. We also have data for

[6]In order to increase the number of countries we would need to considerably shorten the period we analyze. For example, limiting our analysis to 1992-2004 (12 years instead of 25) only adds Belgium. To further add Czech Republic, Slovenia and Sweden we would need to restrict the sample to 1995-2004. In order to preserve the longer time series we focused on the 11 core OECD countries.

[7]Results are robust to throwing away information and harmonizing all countries at the same level of industry aggregation.

intervening years, which we use in some of the robustness checks.

For each country-industry-year cell in our dataset we construct a number of variables. Our main outcome is the wage bill share of workers of different educational groups, which is a standard indicator for skill demand. In 9 of the 11 countries, the high skilled group indicates whether an employee has attained a college degree[8]. A novel feature of our analysis is that we also consider the wage bill of middle skill workers. The precise composition of this group varies across countries, since educational systems differ considerably. But typically, this group consists of high school graduates, people with some college education, and people with non-academic professional degrees.

Our main measure for use of new technology is Information and Communication Technology (ICT) capital divided by value added. Similarly, we also use the measure of non-ICT capital divided by value added. EUKLEMS builds these variables using the perpetual inventory method from the underlying investment flow data for several types of capital (see Data Appendix). For the tradable industries (Agriculture and Manufacturing) we construct measures of trade flows using UN COMTRADE data (21st March 2008 updates)[9]. Details are contained in the Data Appendix.

3.2. Descriptive statistics

3.2.1. Cross Country Trends

Panel A of Table 1 shows summary statistics for the levels of the key variables in 1980 across each country and Panel B presents the same for the changes through

[8] In two countries the classification of high skilled workers is different: in Denmark it includes people in "long cycle" higher education and in Finland it includes people with tertiary education or higher.

[9] Using a crosswalk (available from the authors upon request) we calculate the value of total trade, imports and exports with the rest of the world and separately with OECD and non-OECD countries. We identify all 30 countries that were OECD members in 2007 as part of the OECD.

2004. The levels have to be interpreted with care as exact comparison of qualifications between countries is difficult, which is why wage bill shares are useful summary measures as each qualification is weighted by its price (the wage)[10]. The ranking of countries looks sensible with the US having the highest share of high-skilled (29 percent), followed by Finland (27 percent). All countries have experienced significant skill upgrading as indicated by the growth in the high skilled wage bill share in column (1) of Panel B, on average the share increased form 14.3 percent in 1980 to 24.3 in 2004.

The UK had the fastest absolute increase in the high-skilled wage bill share (16.5 percentage points) and is also the country with the largest increase in ICT intensity. The US had the second largest growth of ICT and the third largest increase in the high-skilled wage bill share (13.9 percentage points), but all countries have experienced rapid increases in ICT intensity, which doubled its 1980 share of value added.

The change of the middle education share in column (2) is more uneven. Although the mean growth is positive, it is relatively small compared to the highly educated (8.7 percentage points on a base of 51.1 percent), with several countries experiencing no growth or a decrease (the US and the Netherlands). The model in Appendix A shows how the wage bill share of the middle skilled could rise as the supply of this type of skill increases, so this supply increase can offset the fall in relative demand caused by technical change. Moreover, as Figure 2A shows, although the wage bill share of the middle group rose more rapidly (in percentage point terms) between 1980 and 1986, it subsequently decelerated. Indeed, in the last six year sub-period, 1998-2004, the wage bill share of middle skilled workers actually fell. At the same time, the wage bill share of low skilled workers continued

[10] Estimating in differences also reduces the suspected bias from international differences as the definitions are stable within country over time.

to decline throughout the period 1980-2004, but at an increasingly slower rate. Figure 2B shows the US, the technology leader that is often a future indicator for other nations. From 1998-2004 the wage bill share of the middle educated declined more rapidly than that of the low skilled workers. Figure 2B is in line with the finding that while college educated US workers continued to gain relative to high-school graduates, high-school graduates gained relatively to college dropouts in the 1980s but not in the 1990s (see Autor, Katz and Kearney, 2008, Figure 5).

3.2.2. Cross Industry Trends

Table 2 breaks down the data by industry. In levels (column (1)) the highly educated were disproportionately clustered into services both in the public sector (especially education) and private sector (e.g. real estate and business services). The industries that upgraded rapidly (column (8)) were also mainly services (e.g. finance, telecoms and business services), but also in manufacturing (e.g. chemicals and electrical equipment). At the other end of the skill distribution, the textile industry, which initially had the lowest wage bill share of skilled workers, upgraded somewhat more than other low skill industries (transport and storage, construction, hotels and restaurants, and agriculture). This raises the issue of mean reversion, so we are careful to later show robustness tests to conditioning on the initial levels of the skill shares in our regressions. In fact, the ranking of industries in terms of skill intensity in 1980 and their skill upgrading over the next 25 years was quite similar across countries. This is striking, because the countries we analyze had different labor market institutions and different institutional experiences over the period we analyze. This suggests something fundamental is at play that cuts across different sets of institutions.

ICT grew dramatically from 1980-2004, accounting for more than 42 percent of the average increase in capital services. The increased ICT diffusion was also quite uneven: financial intermediation and telecoms experienced rapid increases in ICT intensity, while in other industries, such as agriculture, there was almost no increase.

Figures 3, 4, and 5 plot changes by industry in the wage bill shares of high, medium, and low skilled workers respectively against changes in ICT intensity. The top panel of each figure includes all industries with fitted regression lines (solid line for all industry and dashed line for non-traded sectors only). The bottom panel (Figure 3B) restricts attention to the traded sectors. Figure 3A shows that the industries with the fastest ICT upgrading had the largest increase in the high skilled wage bill share. One might be worried that two service sectors, Post and Telecoms and Finance, are driving this result, which is one reason Figure 3B drops all the non-traded sectors. In fact, the relationship between high skill and ICT growth is actually stronger in these "well measured" sectors.

Figure 4 repeats this analysis for the middle educated groups. We observe the exact opposite relationship to Figure 3: the industries with the faster ICT growth had the largest fall in the middle skilled share whether we look at the whole economy (Figure 4A) or just the traded sectors (Figure 4B). Finally, Figure 5 shows that there is essentially no relationship (Figure 5A) or a mildly positive one (Figure 5B) between the change of the share of the least educated and ICT growth.

These figures are highly suggestive of empirical support for the hypothesis that ICT polarizes the skill structure: increasing demand at the top, reducing demand in the middle and having little effect at the bottom. To examine this link more rigorously, we now turn to the econometric analysis.

4. Econometric Results

4.1. Basic Results

Our first set of results for the skill share regressions at the industry by country pair level is contained in Table 3. The dependent variable is the change of the wage bill share of the college-educated in Panel A, the share of the middle educated group in Panel B and the share of the least educated group in Panel C. All equations are estimated in 24 year long differences. The first four columns look across the entire economy and the last four columns condition on the sub-sample of "tradable" sectors where we have information on imports and exports.

Column (1) of Panel A simply reports the coefficient on the constant that indicates that, on average there was a ten percentage point increase in the college wage bill share. This is a very large increase, considering the average skill share in 1980 (across our sample of countries) was only 14%. Column (2) includes the growth in ICT capital intensity. The technology variable has a large, positive and significant coefficient and reduces the regression constant to 8.7. The importance of technology for skill upgrading is consistent with other work, which has found technology-skill complementarity. Column (3) includes the growth of non-ICT capital intensity and value added. The coefficient on non-ICT capital is negative and insignificant, suggesting that there is no sign of capital-skill complementarity. Some studies have found capital-skill complementarity (e.g. Griliches, 1969) but few of these studies have disaggregated capital into its ICT and non-ICT components, so the evidence for capital-skill complementarity may be due to aggregating over high-tech capital that is complementary with skills and lower tech capital that is not. Similarly few studies have looked over such a long time span as we do in this paper. The coefficient on value added growth is positive and significant suggesting that skill upgrading has been occurring more rapidly in the fastest growing sectors (this is consistent with Berman, Rohini and Tan, 2005). Column (4) includes country fixed effects. This is a demanding specification because the specification is already in differences so this specification essentially allows for country specific trends. The coefficient on ICT falls (from 65 to 47) but remains significant at conventional levels[11].

We repeat these specifications for the tradeable industries in the next four columns. Column (5) shows that the overall increase in the college wage-bill share from 1980-2004 was 9 percentage points - similar to that in the whole sample. Columns (6) - (8) add in our measure of ICT and other controls. The coefficient on ICT in the tradeable sector is positive, highly significant and larger than in the overall sample (e.g. 129 in column (8)).

Panel B of Table 3 repeats these specifications for middle-skilled workers. Column (1) shows that overall, the growth of the wage bill share of middle skilled workers has been 8.7 percentage points over this time period. But as the rest of the panel shows, the association between the change in middle-skilled workers and ICT is strongly negative. In column (4), for example, a one percentage point increase in ICT intensity is associated with a 0.8 percentage point fall in the proportion of middle skilled workers. The absolute magnitudes of the coefficients for the sample that includes all industries is quite similar to those for college educated workers.

Panel C holds the low-skilled worker results - the coefficients can all be deduced from the rest of Table 3, but the standard errors are useful to see. Importantly, the technology measures appear to be insignificant for this group of workers illustrating the point that the main role of ICT appears to be in changing demand

[11] Including the mineral extraction sectors caused the ICT coefficient to fall from 47 to 45. We also tried including a set of industry dummies in column (4). All the variables became insignificant in this specification. This suggests that it is the same industries that are upgrading across countries.

between the top and the middle skill groups[12]. Since the adding up requirement means that the coefficients for the least skilled group can be deduced from the other two skill groups we save space by omitting Panel C in the rest of the Tables.

4.2. Robustness and Extensions

4.2.1. Initial conditions

Table 4 examines some robustness checks using the results in our preferred specification of column (4) of Table 3 (reproduced in the first column). Since there may be mean reversion we include the level of initial share of skills in 1980 in column (2). This does not qualitatively alter the results, although coefficient on ICT for the middle skilled does fall somewhat.

4.2.2. Heterogeneity in the coefficients across countries

Wage inequality rose less in Continental Europe than elsewhere, so it is interesting to explore whether technological change induced polarization even there. Columns (3) and (4) restrict the sample to the eight Continental European countries (i.e. Austria, Denmark, Finland, France, Germany, Italy, Netherlands and Spain) and show qualitatively similar results to the pooled sample. Unfortunately, the sample size for most individual countries is rather small preventing a full country by country analysis[13]. For example, column (5) shows that the correlation between ICT and polarization is larger for the US than for the full sample, though column (5) shows that the estimates become imprecise when we control for baseline levels of skill composition.

[12] The difference in the importance of ICT for the middle and lowest skill groups implies that high school graduates are not perfect substitutes for college graduates as Card (2009) argues in the US context. The majority of our data is from outside the US, however, where there are relatively fewer high school graduates.

[13] Due to the above-mentioned restriction that wage bill data is aggregated for some industries in most countries.

4.2.3. Instrumental variables

One concern is that measurement error in the right hand side variables, especially ICT, causes attenuation bias[14]. To mitigate this concern, we use the industry-level measures of ICT in the US in 1980 as an instrument for ICT upgrading over the whole sample. The intuition behind this instrument is that the dramatic global fall in quality-adjusted ICT prices since 1980 (some 15-30% per annum) will disproportionately benefit those industries that (for exogenous technological reasons) have a greater potential for using ICT inputs. An indicator of this potential is the initial ICT intensity in the technological leader, the US. In the 2SLS estimates of column (7) the coefficient on ICT is roughly twice as large as the OLS coefficients for the college educated group (and significant at the 5 percent level), and a little bigger for the middle skill group. Column (8) report estimates the same specification but this time excluding the US itself, and the results are very similar. We also considered using the proportion of routine manual tasks in the industry (in the US in the base year) as an instrument for future ICT growth as these industries were most likely to be affected by falling ICT prices (see Autor and Dorn, 2009). The results of using this instrument are shown in columns (9) and (10). Although the first stages are weaker with this instrument[15], these columns again suggest that we may be under-estimating the importance of ICT by just using OLS - there is certainly no evidence of downward bias.

[14] Estimates of the ICT coefficient for the two 12-year sub-periods of our data are typically about half of the absolute magnitude of those for the full period. In general, our estimates for shorter time periods are smaller and less precise, consistent with the importance of measurement error in the ICT data. For example, in the specification of column (4) of Panel A in Table 3, the coefficient (standard error) on ICT was 18.30 (10.30) in a pooled 12 year regression. We could not reject the hypothesis that the ICT coefficient was stable over time (p-value=0.35).

[15] The signs of the instruments in the first stage are correct. The F-tests is 6.5 in column (7) compared to 10.5 in column (10).

4.2.4. Disaggregating the wage bill into wages and hours

The wage bill share of each skill group reflects its hourly wage and hours worked, and those of the other skill groups. We now discuss estimates of specifications that are identical to those in Table 3, except that they allow for a disaggregation of the dependent variable into the growth of relative skill prices and quantities. In the first two columns of Appendix Table A3 we reproduce the baseline specifications using the log relative wage bill (which can be exactly decomposed) as the dependent variable[16]. Columns (1) - (4) confirm what we have already seem using a slightly different functional form: ICT growth is associated with a significant increase in the demand for high skilled workers relative to middle skilled workers (first two columns) and with a significant (but smaller) increase for low skilled workers relative to middle skilled workers (third and fourth column).

For the high vs. middle skill group, ICT growth is significantly associated with increases in relative wages and relative hours (columns (5), (6), (9) and (10)). In comparing the middle vs. low groups, the coefficients are also all correctly signed, but not significant at conventional levels. Overall this suggests that our results are robust to functional form and the shifting pattern of demand operates both through wages and hours worked[17].

4.3. Trade, R&D and skill upgrading

Having found that technology upgrading is associated with substitution of college-educated workers for middle-skilled workers, we now examine whether changes in

[16] Another functional form check was using the growth rate of ICT intensity. For the specification in column (3) of Panel A in Table 3 we replaced $\Delta(C/Q)$ with $\frac{\Delta(C/Q)}{C/Q}$. The coefficient (standard error) on ICT growth was 2.586 (1.020). The marginal effect of a one standard deviation increase (0.581) is 1.50 (=0.581*2.586), compared with 1.55 (=0.024*64.6) in Table 3.

[17] In examining these results across countries there was some evidence that the adjustment in wages was stronger in the US and the adjustment in hours was stronger in Continental Europe. This is consistent with the idea of great wage flexibility in the US than in Europe.

trade exhibit similar patterns. The first two columns of Table 5 suggest that more trade openness (measured as the ratio of imports plus exports to value added) is associated with increases in the wage bill share of college educated workers, at least once we control for country time trends in column (2). Adding our measures of ICT, value added and non-ICT capital weakens this result in column (3), but the trade measure remains significant. However, the last two columns of Table 5 suggests that when we control for initial R&D intensity the association between trade and skill upgrading becomes much smaller and ceases to be statistically significant. Column (4) repeats the specification of column (3) for the sub-sample where we have R&D data and shows that the trade coefficient is robust. Column (5) includes R&D intensity in a simple specification and shows that the coefficient on trade halves (from 0.5 to 0.24) and is insignificant, whereas the coefficient on R&D is positive and significant at the 10 percent level. In column (6) we include the ICT and non-ICT capital stocks and the coefficient on trade is now 0.11 with a standard error of 0.25. The final column drops the insignificant trade variable and shows that ICT and R&D and individually (and jointly) significant.

These findings are consistent with most of the literature that finds that technology variables have more explanatory power than trade in these kinds of skill demand equations[18]. Of course, trade could be influencing skill demand through affecting the incentives to innovate and adopt new technologies, which is why trade ceases to be important after we condition on technology (e.g. Draca, Bloom and Van Reenen, 2009, argue in favor of this trade-induced technical change hypothesis)[19]. Furthermore, there could be many general equilibrium effects of trade that

[18] These are simple industry-level correlations and not general equilibrium calculations, so we may be missing out the role of trade through other routes.

[19] We further test whether the association between trade and skill upgrading remains similar when we examine different components of trade separately. Appendix Table A4 suggests that when we examine imports and exports separately, the picture is quite similar. Greater trade is associated with an increase in the college wage bill share until we control for initial R&D

we have not accounted for (these are controlled for by the country time effects).

4.4. Magnitudes

We perform some "back of the envelope" calculations in Table 6 to gauge the magnitude of the effect of technology on the demand for highly skilled workers. Column (1) estimates that ICT accounts for 13.2 percent of the increase in the college share in the whole sample without controls and column (2) reduces this to 8.5 percent with controls. Many authors (e.g. Jorgenson, Ho and Stiroh, 2008) have argued that value added growth has been strongly affected by ICT growth, especially in the later period, so column (2) probably underestimates the effect of ICT. Column (3) reports equivalent calculations for the tradeable sectors. Here, ICT accounts for 16.5 percent of the change and R&D a further 16.1 percent, suggesting that observable technology measures by account for almost a third of the increase in demand for highly skilled workers. If we include controls in column (4) this falls to 23.1 percent. Finally, columns (5) and (6) reports results for the IV specification for the whole sample, showing an ICT contribution of ICT of between 22.1 percent and 27.7 percent[20].

We have no general equilibrium model, so these are only "back of the envelope" calculations to give an idea of magnitudes. Furthermore, measurement error probably means that we are probably underestimating the importance of the variables. Nevertheless, it seems that our measures of technology are important in

intensity, in which case the coefficient on trade falls and becomes insignificant. Results are similar when we analyze separately imports to (or exports from) OECD countries. For non-OECD countries the results are again the same, except for exports to non-OECD countries, which remains positively associated with changes in the college wage-bill share even after we add all the controls, including R&D. However, it should be noted that the change in exports to developing countries is on average very small.

[20] The IV specifications for tradeables show an even larger magnitude. For example in a specification with full controls, R&D and ICT combined account for over half of all the change in the college wage bill share. The first stage for the IV is weak, however, with an F-statistic of 6, these cannot be relied on.

explaining a significant proportion of the increase in demand for college educated workers at the expense of the middle skilled.

5. Conclusions

Recent investigations into the changing demand for skills in OECD countries have found some evidence for "polarization" in the labour market in the sense that workers in the middle of the wage and skills distribution appear to have fared more poorly than those at the bottom and the top. One explanation that has been advanced for this is that ICT has complemented non-routine analytic tasks but substituted for routine tasks whilst not affecting non-routine manual tasks (like cleaning, gardening, childcare, etc.). This implies that many middle-skilled groups like bank clerks and para-legals performing routine tasks have suffered a fall in demand. To test this we have estimated industry-level skill share equations distinguishing three education groups and related this to ICT (and R&D) investments in eleven countries over 25 years using newly available data. Our findings are supportive of the ICT-based polarization hypothesis as industries that experienced the fastest growth in ICT also experienced the fastest growth in the demand for the most educated workers and the fastest falls in demand for workers with intermediate levels of education. The effects are nontrivial: technical change (as proxied by ICT and R&D) can account for up to a quarter of the growth of the college wage bill share in the economy as a whole (and more in the tradeable sectors).

Although our method is simple and transparent, there are many extensions that need to be made. First, alternative instrumental variables for ICT would help identify the causal impact of ICT. As with the existing literature, we do not have strong instruments for ICT. Second, although we find no direct role for trade variables, there may be other ways in which globalization influences the labour market, for example by causing firms to "defensively innovate" (Acemoglu, 2003). Third, there are alternative explanations for the improved performance of the least skilled group through for example, greater demand from richer skilled workers for the services they provide as market production substitutes for household production (e.g. childcare, eating out in restaurants, domestic work, etc.)[21]. These explanations may complement the mechanism we address here. Finally, we have not used richer occupational data that would focus on the skill content of tasks due to the need to have international comparability across countries. The work of Autor and Dorn (2009) is an important contribution here.

[21] See Ngai and Pissarides (2007) and Mazzolari and Ragusa (2008).

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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 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 bureaus 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[22].

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

[22] 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.

Table 1: Summary Statistics by Country

Panel A: 1980 levels averaged by country

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Country	**(High-skilled wage-bill share)**	**(Medium-skilled wage-bill share)**	**(Low-skilled wage-bill share)**	**log(Value Added)**	**((ICT capital) / (Value Added))**	**((Non ICT capital) / (Value Added))**	**((Imports+Exports) / (Value Added))**
Austria	8.8	51.6	39.6	8.0	0.012	0.227	1.43
Denmark	5.3	50.5	44.2	7.8	0.029	0.174	2.24
Finland	26.9	28.5	44.6	7.6	0.015	0.195	1.36
France	11.2	49.6	39.2	10.1	0.011	0.158	1.23
Germany	9.4	66.0	24.7	10.3	0.020	0.168	1.31
Italy	5.8	86.9	7.3	9.7	0.021	0.174	0.91
Japan	17.7	49.0	33.2	10.8	0.016	0.230	0.55
Netherlands	21.6	62.1	16.3	8.8	0.012	0.155	3.39
Spain	12.7	9.6	77.7	9.1	0.021	0.265	0.53
UK	9.2	52.7	38.1	9.8	0.019	0.180	1.54
USA	28.7	56.0	15.3	11.6	0.016	0.224	0.54
Mean	14.3	51.1	34.6	9.4	0.018	0.195	0.67

Panel B: Changes from 1980-2004, averaged by country

Country	**Δ (College wage-bill share)**	**Δ (Medium-skilled wage-bill share)**	**Δ (Low-skilled wage-bill share)**	**Δ log(Value Added)**	**Δ ((ICT capital) / (Value Added))**	**Δ ((Non ICT capital) / (Value Added))**	**Δ((Imports+Exports) / (Value Added))**
Austria	5.4	15.5	-20.9	1.2	0.014	0.010	0.87
Denmark	4.1	17.8	-21.9	1.3	0.013	-0.011	1.26
Finland	15.2	12.0	-27.2	1.2	0.022	-0.001	0.36
France	7.7	14.1	-21.8	1.1	0.021	0.066	0.99
Germany	6.3	0.1	-6.4	1.1	0.007	0.023	1.03
Italy	5.3	1.6	-6.9	1.2	0.020	0.051	0.55
Japan	10.8	11.5	-22.3	1.1	0.013	0.035	0.33
Netherlands	13.1	-2.9	-10.1	1.3	0.023	0.041	3.01
Spain	11.9	19.0	-30.9	1.5	0.006	0.056	1.13
UK	16.5	12.6	-29.1	1.3	0.032	-0.031	1.26
USA	13.9	-5.1	-8.8	1.4	0.028	0.032	0.62
Mean	10.0	8.7	-18.8	1.2	0.018	0.025	0.67

Notes: The table reports means weighted by 1980 share of each country's employment. All variables are measured for the full sample, except for trade variables, measured only for traded goods.

Table 2: Summary Statistics by Industry

	1980 levels averaged by industry							Changes from 1980-2004 averaged by industry							Mean weight (share of 1980 employment)	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Code Description	High-skilled wage-bill share	Medium-skilled wage-bill share	Low-skilled wage-bill share	ln(Value Added)	((ICT capital) / (Value Added))	((Non ICT capital) / (Value Added))	((Imports +Exports) / (Value Added))	Δ (High-skilled wage-bill share)	Δ (Medium-skilled wage-bill share)	Δ (Low-skilled wage-bill share)	Δ ln(Value Added)	Δ ((ICT capital) / (Value Added))	Δ ((Non ICT capital) / (Value Added))	Δ ((Imports +Exports) / (Value Added))	Full sample	Traded goods only
Agriculture, hunting, forestry and fishing	5.9	39.7	54.4	0.10	0.002	0.246	0.73	5.1	21.8	-26.9	0.56	0.003	0.009	0.25	0.10	0.28
Food products, beverages and tobacco	6.4	47.7	45.9	0.03	0.012	0.341	1.09	8.0	15.8	-23.9	1.00	0.014	0.010	0.29	0.03	0.09
Textiles, textile products, leather and footwear	5.0	45.8	49.2	0.03	0.006	0.168	2.13	8.2	17.3	-25.4	0.16	0.014	0.027	3.79	0.03	0.09
Wood and products of wood and cork	7.8	46.8	45.4	0.01	0.010	0.232	2.30	9.2	16.4	-25.5	0.93	0.010	0.020	0.02	0.01	0.03
Pulp, paper, paper products, printing and publishing	10.8	51.4	37.8	0.02	0.021	0.242	0.84	11.0	10.9	-21.8	1.17	0.030	0.047	0.02	0.02	0.07
Chemicals and chemical products	13.3	49.2	37.4	0.01	0.016	0.370	2.51	13.1	9.2	-22.2	1.22	0.028	0.070	1.18	0.01	0.04
Rubber and plastics products	9.0	49.1	41.9	0.01	0.010	0.255	0.42	9.8	14.0	-23.8	1.28	0.017	0.022	0.04	0.01	0.02
Other non-metallic mineral products	8.6	47.4	44.0	0.01	0.014	0.270	0.57	9.5	15.3	-24.9	0.90	0.011	0.052	0.13	0.01	0.03
Basic metals and fabricated metal products	8.7	50.1	41.2	0.03	0.010	0.267	1.01	9.1	14.3	-23.4	0.97	0.013	0.009	0.18	0.03	0.10
Machinery, not elsewhere classified	9.8	55.7	34.5	0.03	0.017	0.209	1.59	12.0	8.5	-20.5	1.05	0.023	-0.003	0.98	0.03	0.08
Electrical and optical equipment	12.6	54.7	32.7	0.03	0.024	0.176	3.78	14.6	6.2	-20.8	1.23	0.038	0.052	5.42	0.03	0.08
Transport equipment	10.5	54.9	34.5	0.02	0.010	0.167	1.35	12.3	8.3	-20.6	1.11	0.020	0.080	0.94	0.02	0.06
Manufacturing not elsewhere classified; recycling	7.0	47.7	45.3	0.01	0.013	0.213	3.21	8.2	15.6	-23.8	1.05	0.010	0.004	0.41	0.01	0.04
Sale, maintenance and repair of motor vehicles and motorcycles; retail sale of fuel	6.5	59.6	33.9	0.02	0.016	0.195		8.5	9.7	-18.1	1.3	0.0	0.0		0.02	
Wholesale trade and commission trade, except of motor vehicles and motorcycles	10.2	57.1	32.6	0.05	0.032	0.247		10.2	7.7	-17.8	1.42	0.030	0.055		0.05	
Retail trade, except of motor vehicles and motorcycles; repair of household goods	8.3	58.1	33.6	0.09	0.011	0.084		8.7	9.1	-17.8	1.29	0.016	0.079		0.09	
Transport and storage	6.1	53.7	40.2	0.04	0.020	0.200		7.0	13.5	-20.5	1.36	0.030	0.072		0.04	
Post and telecommunications	8.1	60.5	31.4	0.02	0.143	0.238		17.2	1.9	-19.2	1.60	0.088	0.119		0.02	
Real estate activities	26.8	52.4	20.8	0.01	0.014	0.891		12.7	-1.1	-11.6	1.81	0.014	-0.008		0.01	
Renting of machinery and equipment and other business activities	29.3	51.2	19.5	0.05	0.051	0.180		18.1	-7.1	-11.0	2.16	0.020	-0.027		0.05	
Construction	7.3	52.1	40.6	0.08	0.005	0.180		4.0	16.2	-20.2	1.19	0.009	0.013		0.08	
Hotels and restaurants	6.2	54.4	39.4	0.04	0.013	0.136		7.8	12.5	-20.3	1.59	0.000	0.041		0.04	
Financial intermediation	18.3	65.0	16.6	0.03	0.051	0.297		19.6	-8.2	-11.3	1.57	0.112	0.009		0.03	
Public admin and defence; compulsory social security	20.8	58.4	20.7	0.07	0.017	0.171		13.1	0.7	-13.7	1.30	0.019	-0.022		0.07	
Education	51.7	38.2	10.1	0.06	0.013	0.078		11.6	-5.4	-6.1	1.47	0.004	-0.010		0.06	
Health and social work	27.0	53.1	19.8	0.07	0.011	0.119		11.5	0.8	-12.2	1.70	0.003	-0.008		0.07	
Other community, social and personal services	18.4	50.1	31.5	0.04	0.038	0.215		11.2	7.1	-18.3	1.65	0.003	0.029		0.04	

Notes: Industry values are simple unweighted averages across all countries. Regressions in subsequent tables use the maximum level of disaggregation available in each country (method described in Data Appendix).

Table 3: Changes in Wage Bill Shares: 1980-2004

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A:Dependent variable: High-Skilled Wage Bill Share								
Δ ((ICT capital) / (Value Added))		72.29	64.56	46.92		163.94	139.6	128.71
		(18.28)	(17.31)	(14.94)		(45.48)	(42.74)	(32.19)
Δ log(Value Added)			5.42	4.76			3.26	3.41
			(1.24)	(0.95)			(2.25)	(1.07)
Δ ((Non ICT capital) / (Value Added))			-7.64	-6.45			0.31	-0.47
			(4.92)	(3.51)			(5.59)	(2.45)
Intercept	10.02	8.69	2.22		9.12	6.42	4.04	
	(0.57)	(0.63)	(1.67)		(0.86)	(1.02)	(2.19)	
Country fixed effects				X				X
Sample: All industries	X	X	X	X				
Sample: Traded industries					X	X	X	X
Obs.	208	208	208	208	84	84	84	84
R-squared		0.09	0.19	0.45		0.19	0.22	0.81
Panel B:Dependent variable: Medium-skilled Wage Bill Share								
Δ ((ICT capital) / (Value Added))		-100.78	-77.76	-64.52		-163.98	-41.59	-288.01
		(30.21)	(25.44)	(20.24)		(115.77)	(84.73)	(83.94)
Δ log(Value Added)			-13.8	-15.33			-15.64	-7.96
			(2.69)	(2.23)			(4.27)	(3.14)
Δ ((Non ICT capital) / (Value Added))			9.76	18.01			-10.79	1.57
			(11.88)	(10.25)			(14.08)	(10.98)
Intercept	8.73	10.59	27.24		15.5	18.20	29.75	
	(1.29)	(1.49)	(3.73)		(1.90)	(2.95)	(4.67)	
Country fixed effects				X				X
Sample: All industries	X	X	X	X				
Sample: Traded industries					X	X	X	X
Obs.	208	208	208	208	84	84	84	84
R-squared		0.05	0.23	0.58		0.05	0.25	0.74
Panel C:Dependent variable: Low-skilled Wage Bill Share								
Δ ((ICT capital) / (Value Added))		28.55	13.21	17.71		0.50	-97.91	159.65
		(27.34)	(25.66)	(16.41)		(113.51)	(100.71)	(79.30)
Δ log(Value Added)			8.43	10.62			12.45	4.61
			(2.40)	(1.95)			(4.24)	(3.30)
Δ ((Non ICT capital) / (Value Added))			-2.21	-11.68			10.32	-1.28
			(9.63)	(9.07)			(11.91)	(11.73)
Intercept	-18.74	-19.26	-29.5		-24.61	-24.62	-33.84	
	(1.12)	(1.31)	(3.27)		(1.68)	(2.55)	(3.95)	
Country fixed effects				X				X
Sample: All industries	X	X	X	X				
Sample: Traded industries					X	X	X	X
Obs.	208	208	208	208	84	84	84	84
R-squared		0.00	0.10	0.65		0.00	0.16	0.70

Notes: Coefficients estimated by OLS with robust standard errors in parentheses. Regressions in columns (1)-(4) weighted by each industry's 1980 share of each country's employment, and regressions in columns (5)-(8) weighted by each industry's 1980 share of each country's employment in traded industries.

Table 4: Changes in Wage Bill Shares: 1980-2004 - Robustness checks

Panel A: Dependent variable: High-Skilled Wage Bill Share

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	OLS	OLS	OLS	OLS	OLS	OLS	2SLS	2SLS	2SLS	2SLS
Δ ((ICT capital) / (Value Added))	46.92	42.09	50.98	48.79	132.84	66.1	121.63	103.16	137.99	65.31
	(14.94)	(14.66)	(16.64)	(16.20)	(52.59)	(58.15)	(53.43)	(48.82)	(119.44)	(104.60)
Δ log(Value Added)	4.76	2.93	5.79	4.4	0.26	-1.97	4.24	4.85	4.12	5.09
	(0.95)	(1.39)	(1.31)	(1.93)	(2.94)	(3.79)	(1.07)	(1.10)	(1.30)	(1.20)
Δ ((Non ICT capital) / (Value Added))	-6.45	-5.06	-9.25	-8.19	15.41	2.56	-8.47	-9.85	-8.91	-8.54
	(3.51)	(3.99)	(4.56)	(5.13)	(12.99)	(12.94)	(4.02)	(4.33)	(5.01)	(5.16)
1980 High-skilled wage bill share		0.06		0.04		0.34				
		(0.06)		(0.07)		(0.19)				
1980 Medium-skilled wage bill share		0.12		0.08		0.6				
		(0.05)		(0.07)		(0.27)				
Country fixed effects	X	X	X	X			X	X	X	X
Sample: Continental Europe			X	X						
Sample: US					X	X				
Sample: All countries	X	X					X		X	
Sample: All countries except USA								X		X
Obs.	208	208	143	143	27	27	208	181	208	181
R-squared	0.450	0.47	0.44	0.45	0.21	0.43	0.36	0.38	0.32	0.46
F-stat for excluded instrument in the first stage							10.5	9.6	6.5	8.3

Panel B:Dependent variable: Medium-Skilled Wage Bill Share

	OLS	OLS	OLS	OLS	OLS	OLS	2SLS	2SLS	2SLS	2SLS
Δ ((ICT capital) / (Value Added))	-64.52	-41.72	-62.13	-51.41	-160.15	-80.06	-73.81	-46.74	-42.8	22.21
	(20.24)	(13.35)	(18.79)	(14.28)	(44.52)	(60.97)	(56.75)	(49.04)	(235.73)	(224.74)
Δ log(Value Added)	-15.33	-2.73	-16.33	-4.36	-7.57	0.45	-15.26	-16.24	-15.48	-16.67
	(2.23)	(1.99)	(3.13)	(2.83)	(3.32)	(3.64)	(2.30)	(2.47)	(2.27)	(2.34)
Δ ((Non ICT capital) / (Value Added))	18.01	3.89	21.33	7.82	-16.58	-7.9	18.26	20.02	17.42	17.62
	(10.25)	(6.61)	(13.38)	(9.27)	(17.77)	(13.85)	(10.59)	(11.41)	(11.34)	(12.81)
1980 High-skilled wage bill share		-0.55		-0.48		-0.72				
		(0.08)		(0.08)		(0.19)				
1980 Medium-skilled wage bill share		-0.64		-0.57		-0.95				
		(0.07)		(0.09)		(0.28)				
Country fixed effects	X	X	X	X			X	X	X	X
Sample: Continental Europe			X	X						
Sample: US					X	X				
Sample: All countries	X	X					X		X	
Sample: All countries except USA								X		X
Obs.	208	208	143	143	27	27	208	181	208	181
R-squared	0.580	0.79	0.59	0.77	0.36	0.68	0.58	0.78	0.58	0.52
F-stat for excluded instrument in the first stage							10.5	9.6	6.5	8.3

Notes: Coefficients estimated by OLS with robust standard errors in parentheses. Regressions weighted by the industry's 1980 share of each country's employment. In columns (7) and (8) we instrument the 25-year difference in ICT Capital/Value Added by the 1980 levels of ICT capital/Value Added in the USA. In columns (9) and (10) we instrument the 25-year difference in ICT Capital/Value Added by the 1980 levels of routine task input using the 1991 Directory of Occupational Titles (constructed as in Autor, Levy and Murnane (2003)).

Table 5: Trade and Technology

Dependent variable: High-Skilled Wage Bill Share							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Δ ((Imports+ Exports) / (Value Added))	0.59	0.71	0.59	0.50	0.24	0.11	
	(0.46)	(0.25)	(0.15)	(0.19)	(0.30)	(0.25)	
Δ ((ICT capital) / (Value Added))			107.61	94.25		73.59	75.49
			(31.70)	(34.07)		(31.41)	(31.10)
Δ log(Value Added)			4.09	3.84	4.03	2.57	2.36
			(1.09)	(1.26)	(1.38)	(1.52)	(1.35)
Δ ((Non ICT capital) / (Value Added))			-0.63	0.16		0.97	1.03
			(2.41)	(3.41)		(3.12)	(3.02)
1980 (Research and Development Expenditure/ Value Added)					34.18	28.04	30.08
					(18.23)	(17.59)	(14.91)
Intercept	8.60						
	(0.80)						
Country fixed effects		X	X	X	X	X	X
Sample: Traded goods (all countries)	X	X	X				
Sample: Traded goods (except Austria and Spain)				X	X	X	X
Obs.	84	84	84	65	65	65	65
R-squared	0.02	0.67	0.82	0.80	0.80	0.82	0.82

Notes: 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 (4)-(7)).

Table 6: 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 5 column (7)		Table 4 column (7)
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		

Notes: 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

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

Note: We aggregate to the lowest level of industries in each country where there is a unique value of the wage bill share for each education group

Appendix Table A3: Decomposing Changes in Relative Wage Bills into Wages and Hours

Dependent variable	Ln(Relative Wage Bill)				Ln(Relative Wages)				Ln(Relative Hours Worked)			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	(High-skilled/Medium-skilled)		**(Medium-skilled/Low-skilled)**		**(High-skilled/Medium-skilled)**		**(Medium-skilled/Low-skilled)**		**(High-skilled/Medium-skilled)**		**(Medium-skilled/Low-skilled)**	
Δ ((ICT capital) / (Value Added))	4.72	4.00	-2.47	-2.04	1.28	0.93	-0.62	-0.77	3.44	3.07	-1.85	-1.28
	(1.36)	(1.26)	(1.07)	(0.99)	(0.48)	(0.43)	(0.60)	(0.68)	(1.33)	(1.26)	(1.14)	(1.12)
Δ log(Value Added)		0.18		-0.28		0.10		0.04		0.08		-0.32
		(0.09)		(0.08)		(0.06)		(0.07)		(0.09)		(0.10)
Δ ((Non ICT capital) / (Value Added))		0.98		0.14		0.41		0.18		0.57		-0.03
		(0.51)		(0.38)		(0.21)		(0.17)		(0.51)		(0.34)
Country fixed effects	X	X	X	X	X	X	X	X	X	X	X	X
Sample: All industries	X	X	X	X	X	X	X	X	X	X	X	X
Obs.	208	208	208	208	208	208	208	208	208	208	208	208
R-squared	0.32	0.38	0.72	0.75	0.28	0.33	0.43	0.44	0.32	0.33	0.52	0.56

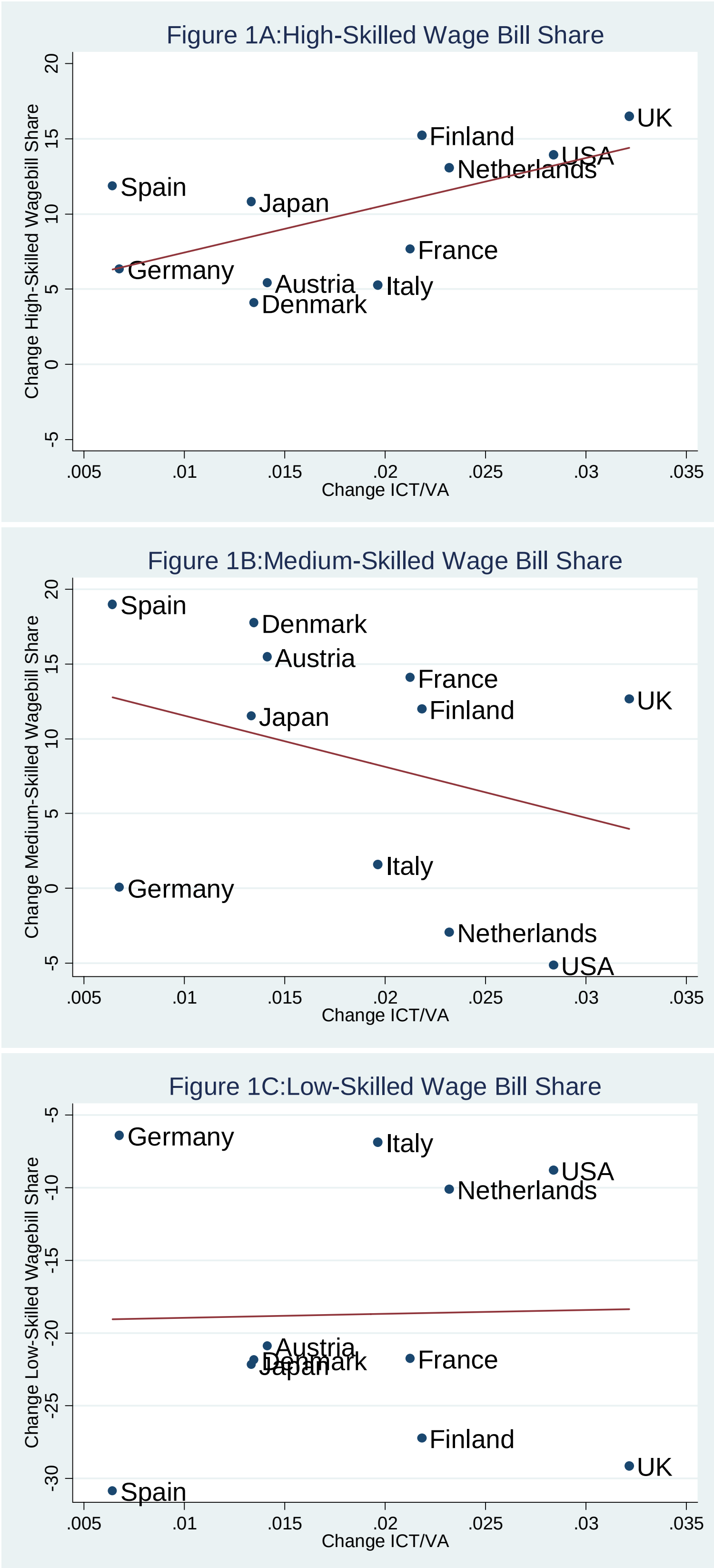
Notes: Dependent variable in columns (1)-(4) is the 1980-2004 change in the Ln(relative wage bill), e.g. in column (1) this is ln(wage bill of highly skilled workers) - ln(wage bill of medium skilled workers). The dependent variable in columns (5)-(8) is the change in Ln(relative hourly wage), e.g. in column (5) it is the ln(hourly wage of highly skilled) - ln(hourly wage of medium skilled). In columns (9)-(12) the dependent variable is the change in Ln(relative hours worked), e.g. in column (9) this is ln(annual hours of highly skilled) - ln(annual hours of medium skilled) . Coefficients estimated by OLS with robust standard

Appendix Table A4: Trade, ICT, and Research and Development

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
Dependent variable: High-Skilled Wage Bill Share																		
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 log(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

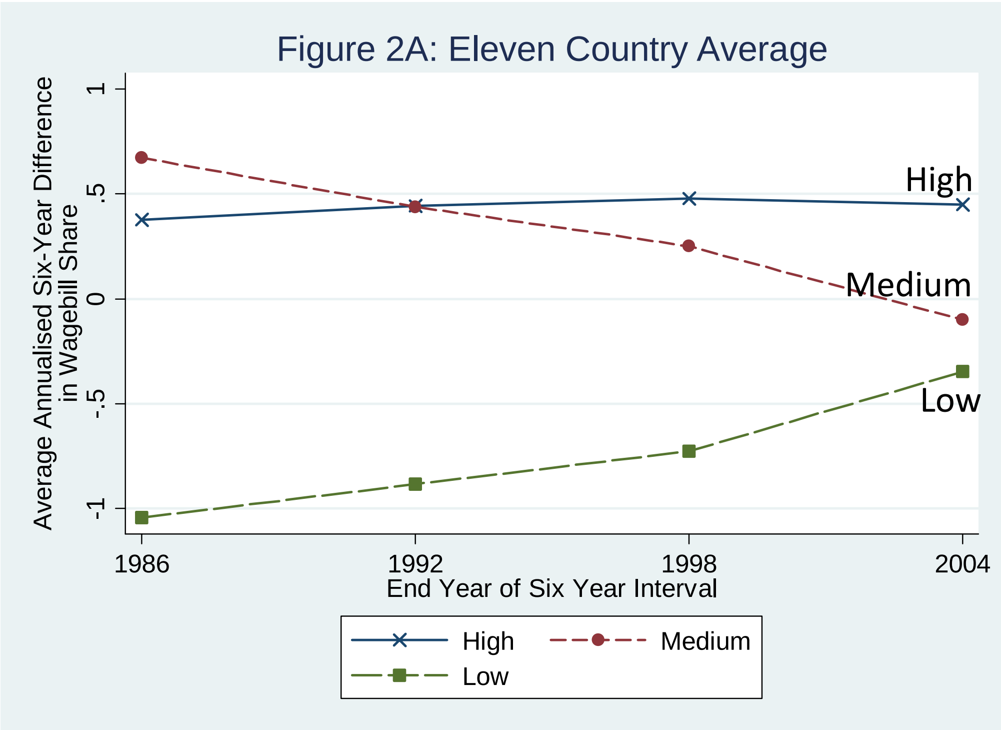
Notes: Coefficients estimated by OLS with robust standard errors in parentheses. Regressions weighted by the industry's 1980 share of each country's employment, for traded goods. The OECD ANBERD dataset does not have R&D data for Austria and Spain, which are dropped from the sample

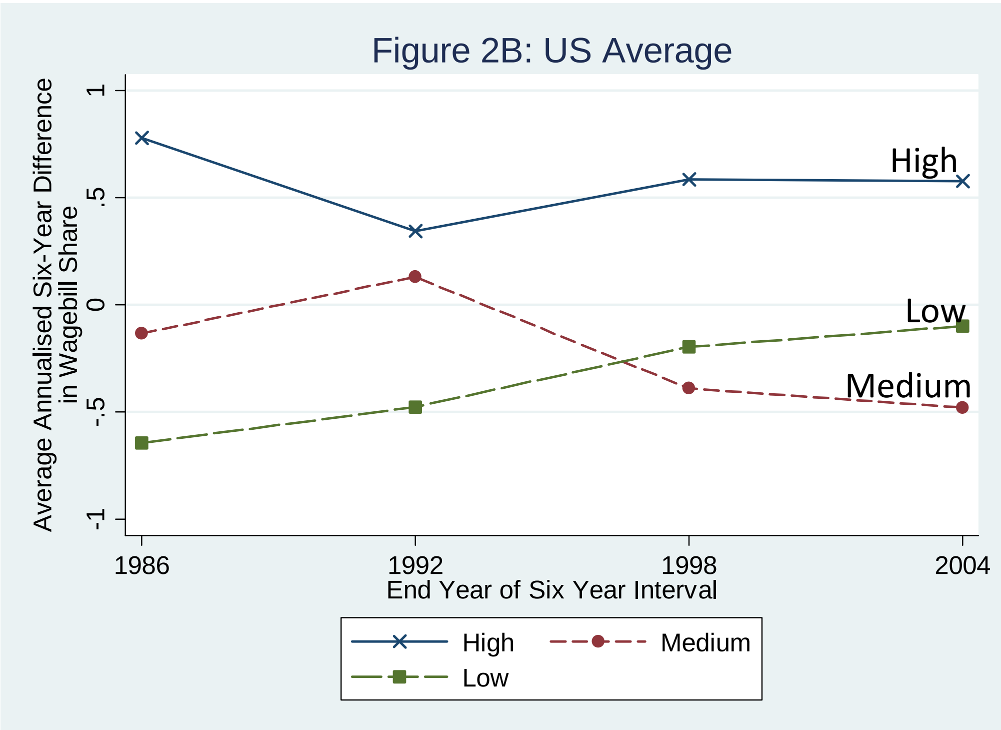
Figure 1: Cross Country Variation in Growth of High, Medium and Low-Skilled Wage Bill Shares and ICT Intensity, 1980-2004



Note: Figure 1 plots the growth of high, medium and low-skilled college wage bill shares against the growth of ICT intensity (ICT/VA) for 11 OECD countries (see Table 1). Lines show regressions of the growth of each wage bill share against growth of ICT intensity.

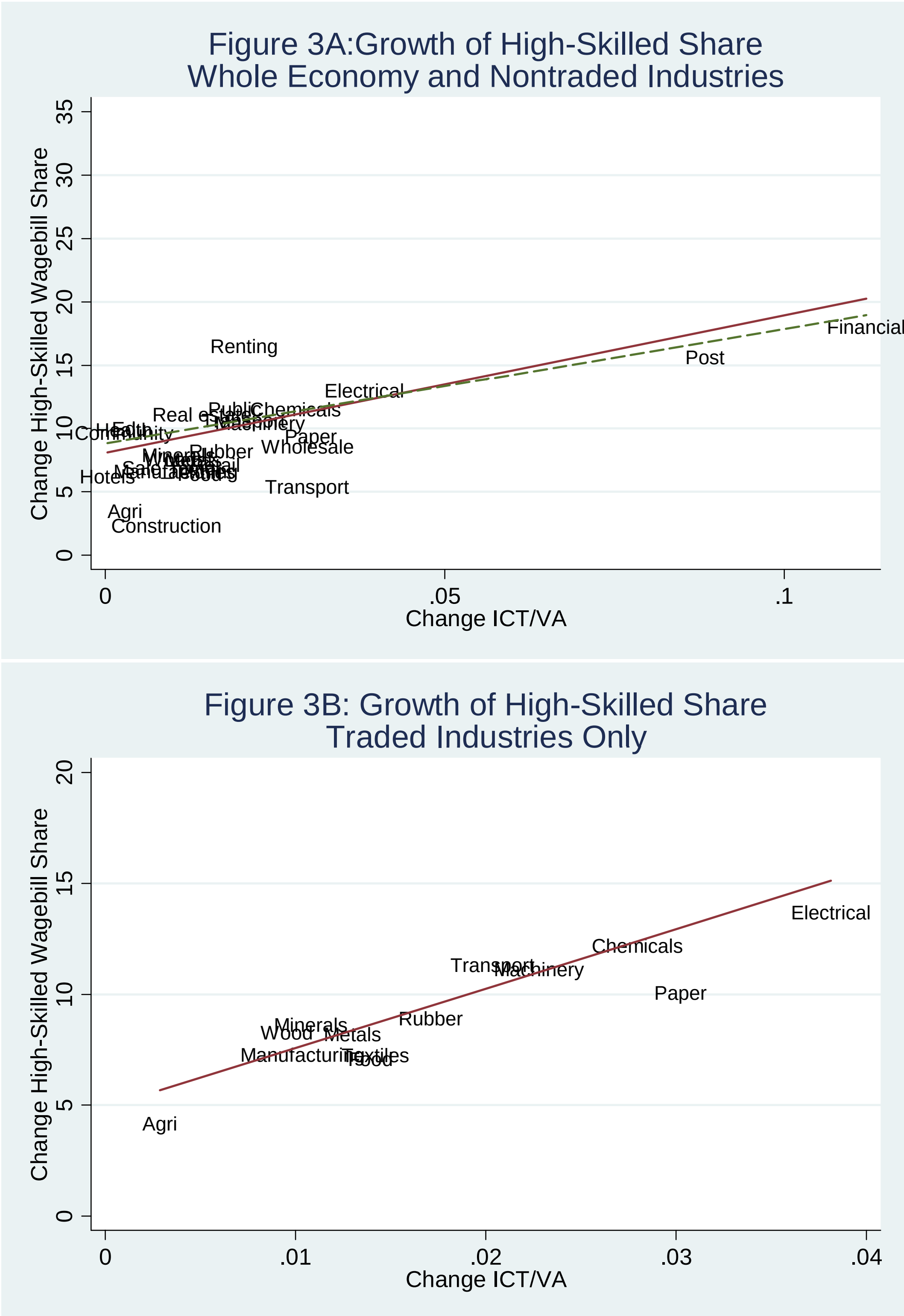
Figure 2: Average Annual Percentage Point Changes in High, Medium and Low-Skilled Wage Bill Shares over Six-Year Intervals from 1980-2004 (Eleven Country Average and US)





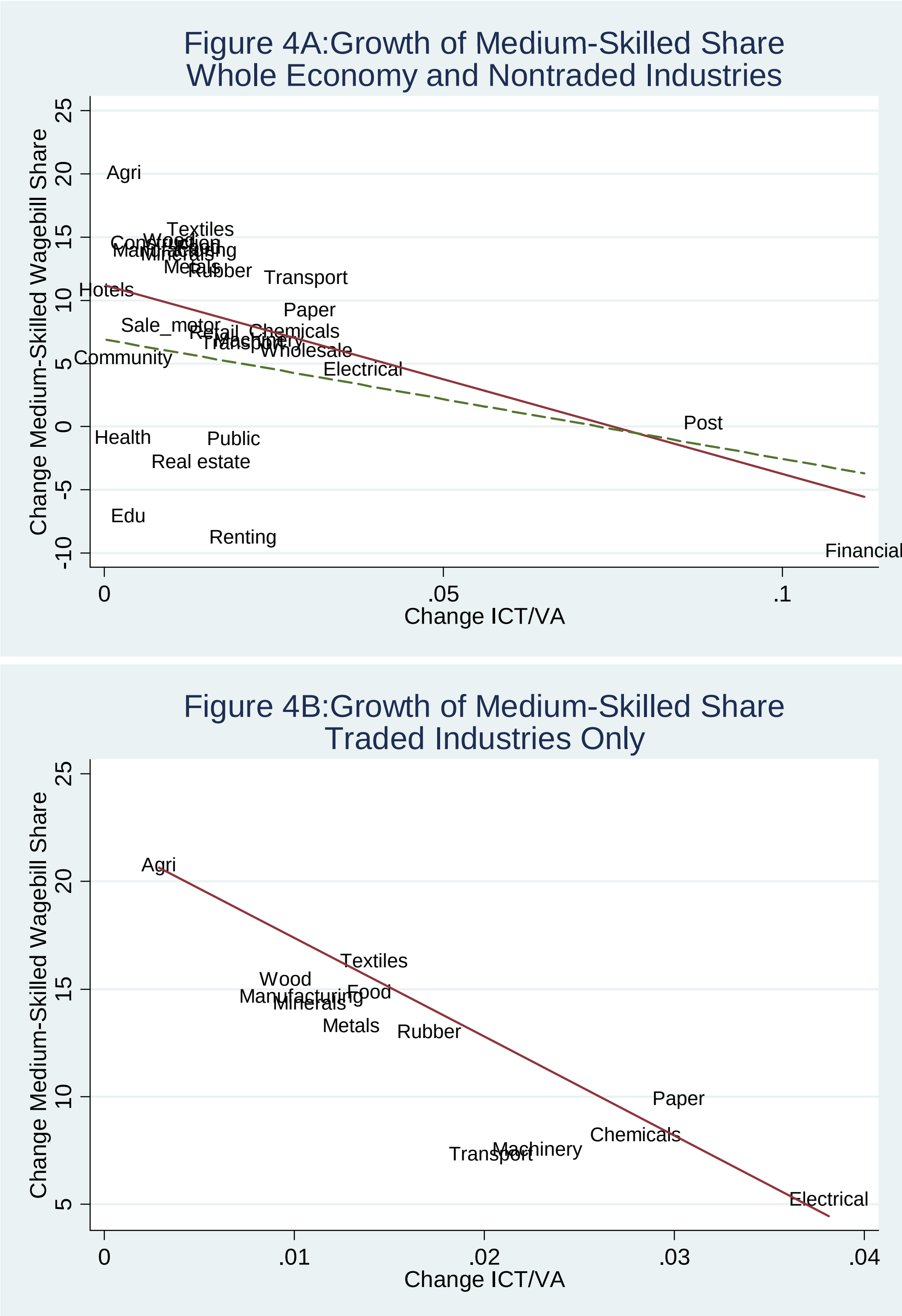
Note: Figure 2 shows annualised six-year average growth rates of high, medium and low-skilled wage bill shares from 1980-2004, weighted by employment share in the starting year of the six-year interval (e.g. The 1980-1986 annualised difference is weighted by each industry's share in the 1980 employment of the country).

Figure 3: Cross-Industry Variation in Growth of High-Skilled Wage-Bill Share and ICT Intensity, 1980-2004 (11 Country Means)



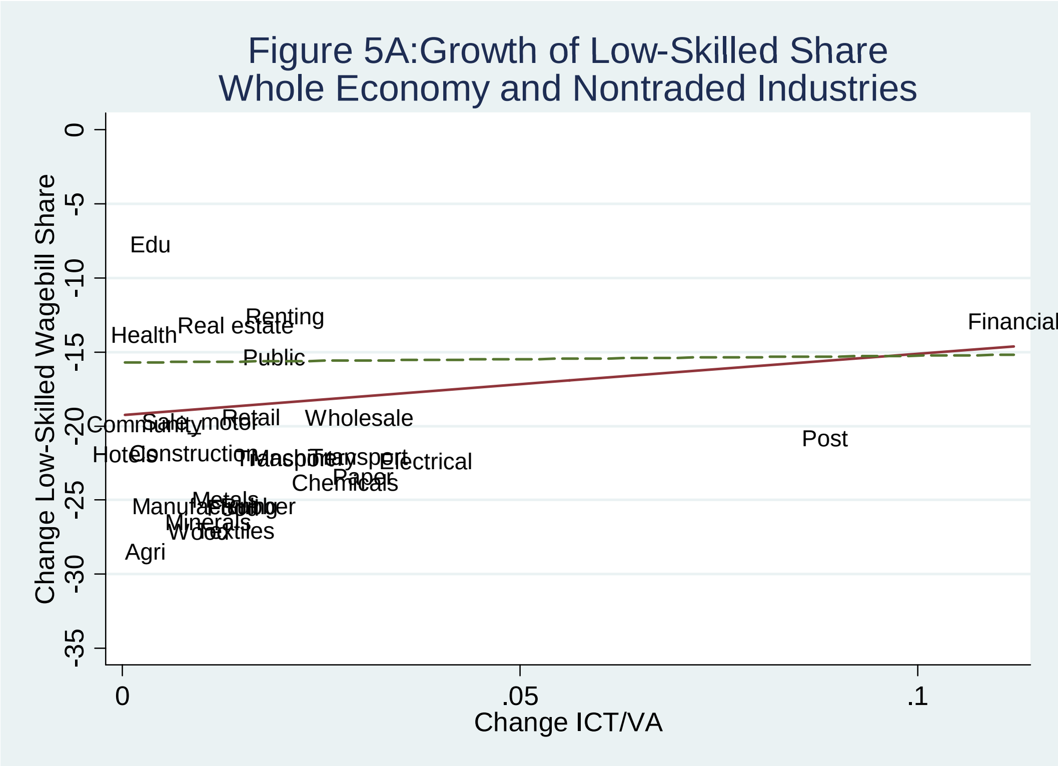
Note: Figure 3A plots the growth from 1980-2004 of high-skilled wage bill shares against the growth of ICT intensity (ICT/VA), by industry, averaged across countries. Lines show fitted values from regressions weighted by the cross-country average of each industry's share in 1980 employment (solid line for entire economy, dashed line for non-trade industries only). Figure 3B restricts the sample to traded industries.

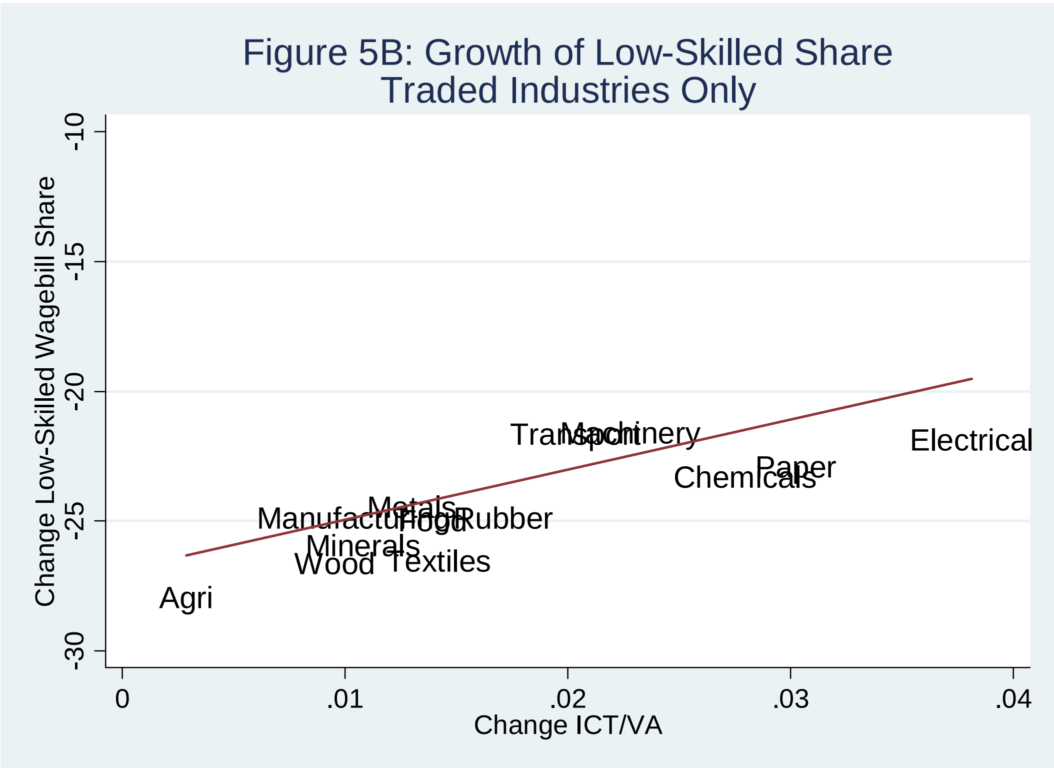
Figure 4: Cross-Industry Variation in Growth of Medium-Skilled Wage-Bill Share and ICT Intensity, 1980-2004 (11 Country Means)



Note: Figure 4A plots the growth from 1980-2004 of medium-skilled wage bill shares against the growth of ICT intensity (ICT/VA), by industry, averaged across countries. Lines show fitted values from regressions weighted by the cross-country average of each industry's share in 1980 employment (solid line for entire economy, dashed line for non-trade industries only). Figure 4B restricts the sample to traded industries.

Figure 5: Cross-Industry Variation in Growth of Low-Skilled Wage-Bill Share and ICT Intensity, 1980-2004 (11 Country Means)





Note: Figure 5A plots the growth from 1980-2004 of low-skilled wage bill shares against the growth of ICT intensity (ICT/VA), by industry, averaged across countries. Lines show fitted values from regressions weighted by the cross-country average of each industry's share in 1980 employment (solid line for entire economy, dashed line for non-trade industries only). Figure 5B restricts the sample to traded industries.