Computers and Pay

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By Francis Green[*], Alan Felstead[**], Duncan Gallie[***] and Ying Zhou[***]

[*]Kent University, [**]Cardiff University, [***]Nuffield College, Oxford University

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Editor's Foreword

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Abstract

This paper describes the diffusion of computer use among jobs in Britain, and shows that the technology is having notable effects on the labour market. By 2006 three in four jobs entailed job-holders using computers, while for two in four jobs computer use was 'essential'. Computing skills have a significant impact on pay but, in 2006, much of this effect is interactive with influence skills. The average effect of a unit increase in the Computing Skills index (which ranges from 0 to 4) is to raise pay by an estimated 5.3% and 6.0% for men and women respectively. For men there is an additional 19.2% boost to pay in establishments where at least three quarters of workers are working with computers, compared to establishments where no one uses computers. These effects are greater for those people in jobs with above-average influence skills requirements. Our estimates allow for education, a large number of other generic skills and other conventional controls, which makes them more robust to the critique that they are overestimates because they might suffer from omitted skill bias. IV estimates show only small differences from the OLS estimates. We also find that the direct and interactive effects of computer skills and influence skills have risen over the decade, indicating increased scarcity.

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Introduction.

Although it is widely claimed that the introduction of information technologies has transformed the nature of employment in the modern era, understanding of how computers have been affecting the lives of workers is far from comprehensive. In this paper we present some new evidence about the growth of computer usage at work. We also investigate the link between computer skills and pay in Britain, which is one of several contentious issues among social scientists attempting to understand the growth of economic inequality.

The last ten years has witnessed a major expansion in the use of ICT in organisations. Investment in computer software reached 2% of GDP in 2002 after a five-year period of rapid growth (Abramovsky and Griffith, 2007) and an accelerated expansion of overall ICT investment from £13 billion in 1992 to more than £35 billion in 2000 (National Statistics, 2007). Even so, the spread of ICT among the UK population was far from complete by 2005, with one in four 16-74 year olds professing not even basic computing skills, according to official European Union data; digital access remains differentiated along lines of age and education (Demunter, 2005, 2006).

Recent evidence has shown that the impact of ICT investment on UK productivity is substantial, and that ICT played the dominant role in explaining productivity growth in the 1990s (Crespi et al., 2007; Oulton and Srinivasan, 2005). In the US, the productivity boom since the mid-1990s is strongly linked to ICT investment (Draca et al. 2006)). Studies also find that the effects of new ICT projects are especially high in the long-term, because of their complementarity with investments in organisational change (Brynjolfsson and Hitt, 2000). With these impacts from such a pervasive and fast-growing new technology, it would seem quite plausible that the required skills should, for a time at least, be scarce, given that access to acquiring the skills is constrained and costly. If the labour market value of the skills is high enough, technology may become part of the process through which income gaps are widened and the low-skilled excluded from rising affluence as a consequence of the 'digital divide'. The rising demand for computer skills contributes to the increased demand for highly qualified workers (Green et al., 2003); and, beyond schooling, if access to acquiring computing skills is adversely distributed (whether by institutional constraints, age, or ability) then the technology becomes a route towards inequality. It is in part for these reasons that computer skills training has been embedded in the school curriculum, and in the life-long learning agenda, and is now a major focus for European Union initiatives.

It has long been recognised that computer usage, even at quite simple levels, is associated with higher pay. Raw calculations show that, in 2006, on average computer users (for the moment undifferentiated, see below) earned 63% more than non-computer users. But much of this gap is evidently associated with other characteristics – chiefly, prior education – rather than computer skills as such. It is important to try to discover how much (if at all) computing skills have a causal effect on pay, once other factors have been isolated and controlled for. A 'large' impact calls for renewed efforts to support computer skills training, for both egalitarian and efficiency reasons. If the impact is low or non-existent, policy-makers had best look to other factors behind rising inequality, such as inadequate general education or reduced protection for low-paid workers. Yet labour economists have so far failed to come up with a consensual assessment of the computer's effect. While Krueger (1993), in a seminal paper on the 1980s US labour market, proposed that a pay premium of between 10 and 15% for computer use could explain a substantial part of the rising return to schooling – and while others have confirmed the pay premium in the US and elsewhere – an influential opposing group have held that the computing pay premium is merely a reflection of unobserved ability which would have led computer-users to receive higher pay anyway, irrespective of the technology. Put another way, the critique is that the computer revolution affected those workers who were already being paid more by virtue of their occupational or industrial status or of some latent but enduring individual quality.

Reconfirmation and extension of Krueger's US evidence has come from a number of studies which range over methods, time and place. Methods vary according to the extent to which they are able to control for the many other characteristics of jobs that could affect both pay and the likelihood of using computers. Three approaches can be used. One can include a large number of job characteristics in an attempt to control for observed heterogeneity. However, this approach is rare, owing to lack of data. One can, alternatively, use instrumental variables to control for the endogeneity of computer usage. Finally, some studies use limited panel data to try to eliminate potential biases attributable to unobserved but fixed heterogeneous characteristics. In the US Goss and Phillips (2002) find support for a substantial computer skills premium, but their data do not allow extensive controls for either personal or job characteristics. Dunne et al. (2004) find an impact at firm level from investment in computers on wages. There is confirmation also in Canada (Pabilonia and Zoghi, 2005) where controls for fixed effects reduce the estimated computer pay premium for current computer usage to an insignificant amount, but still leave a substantial premium (13%) for computer-users that have had average prior experience with computers. For Australia, Borland et al. (2004) find a substantial premium, but the earnings effect is found to be specified better by the number and level of computer skills than by a simple computer-use dummy variable. Studies in some developing countries are also supportive (e.g. Ng (2006) for Shanghai, Liu et al. (2004) for Taiwan).

In Britain, several studies find that there is a substantive pay premium for computer users. Arabsheibani et al. (2004) using 1980s data from the British Social Attitudes Survey, found large returns (22% to 26%), rising to a surprising 37% when seemingly taking account of selection. Arabsheibani and Marin (2006), however, using the 5th sweep of the National Child Development Study (NCDS) in 1991, report lower estimates ranging from 7 to 17%. Both these studies use rather old data, which throw little light on recent changes since computers have become pervasive in British jobs (see below), and the authors appear unaware of the existence of more recent data and studies. More pertinent to recent developments is the analysis of Dolton and Makepeace (2004), which makes use of both the 5th (1991) and 6th (2000) waves of the NCDS; they find that during the 1990s there was a computer use premium for women of between 10% and 12%, and for men of between 9% and 13%. Hildreth (2001) finds that email usage carries with it a premium in 1998, but also suggests that much of the premium may be associated with unobserved complementary skills which only some managers choose to use. Finally, Green (1998) and Dickerson and Green (2004), using data from the 1997 and 2001 Skills Surveys, find substantial effects from using computers at different levels. A distinctive finding of the latter studies, which include controls for a large number of job-related variables and use pseudo-panel techniques, is that more sophisticated computer usage brings higher returns, as one might expect. In 2001 the premium ranged from 8% to 21% depending on the level of computer use.

Set against these confirmatory studies implying a substantial premium are those which claim to show that the premium for computer skills is zero. Frequently cited is the somewhat derisive study by Dinardo and Pischke (1997) which reasoned against Krueger's findings as follows. Using early German data they find that using pencils (or other simple and widely used tools) is associated with a pay differential similar to that for computer use; and, since it is implausible to infer that the skill to use pencils causes pay to rise by, say, 13% (they ascribe the appearance of this gap to unobserved skills), they prefer to believe the same must be true of computers. Unfortunately for this analysis, however, the list of job characteristics is quite attenuated, so they were unable to investigate whether a more comprehensive data set on jobs would have allowed them to eliminate the pencils premium but not the computer premium (see Dickerson and Green, 2004, who show precisely this effect in Britain). We therefore consider the 'pencils' critique to be unsubstantiated. Nevertheless, the point remains that exclusion of complementary skills from analyses is a pervasive potential source of bias, usually over-estimation, in the coefficients attached to individual skills which, if ignored, can lead to false inferences about the role of computers in generating inequality. Handel (2007) shows that, after including measures of seven detailed job tasks and pre-computing-revolution occupational and industry mean wages in his regressions, the impact of using a pc or terminal in the US in 1991 is very much reduced and in one specification rendered altogether insignificant. An alternative approach is to try to measure computer skills directly. Direct assessment data on computer skills are not currently available for this purpose. Borghans and ter Weel (2004) use some indirect, self-assessment measures of skill available in the 1997 Skills Survey (Ashton et al., 1999), and find that the self-assessment measure of computer skill is not related to pay once computer use is controlled for; however, they do not consider the downward bias resulting from the probable considerable measurement error related to self-assessment.

Of some interest are panel studies which with conventional estimators claim to eliminate the biases associated with unobserved personal or job characteristics. Entorff and Kramarz (1997) find, using French data, that fixed effects estimates show much smaller and statistically insignificant pay premia associated with immediate take-up of computers, but report that there is a return of approximately 1% per year of experience using computers. At that rate, it would not take long for the impact of computers to be noticeable. Kuku et al. (2007), also using panel data, come to the conclusion that there is no pay premium in Russia. Also claiming to eliminate fixed-effects bias, a twins-based study in the US (Krashinsky, 2004) finds a statistically insignificant pay premium of 7%. There are, however, reasons to be cautious about the preference for conventional panel fixed-effects estimates. First, the panel estimates generally rely on relatively crude dynamic assumptions, often assuming that computers' boost to wages (if it exists) should be instantaneous. However, it seems much more plausible to assume that computing skills take time to acquire, and Entorff and Kramarz's finding confirms this. Second, the possible biases from dynamic mis-specification are compounded by the danger of large measurement errors. In the Entorff and Kramarz panel, for example, the date at which computers started to be used is imputed by use of an untested recall question in the third year of the panel. In Krashinsky's twins sample the problem is confounded by a small sample size (381 twin pairs, with an unreported number of cases of between-twin differences in computer usage). The standard errors are unsurprisingly high, making it easy to accept a null hypothesis that computers have no effect. If, however, the null hypothesis were that the effect is much higher (e.g. the 10% of Krueger's study – why not?) this also could not be rejected, even though the author reports that the impact of computers 'disappeared' (Krashinsky, 2004: 88). Third, Dolton and Makepeace (2004) find that conventional panel fixed-effect estimators can be flawed by assuming that the impact of computers is homogeneous across groups of computer-users and across time. They found different premia among male computer-users according to when they started using computers. Fourth, fixed-effects estimators can be downward biased if wages are downwardly rigid, or if computer-users are still indirectly paying the cost of acquiring computer skills at around the time that their use of computers is being measured. For these reasons, panel estimates should not necessarily be preferred, in this case, over cross-section estimates that can include a wide range of job characteristics or can otherwise satisfactorily allow for the endogeneity of computer usage.

We have described, so far, what studies have shown about the impact of computers on pay, and found a conflicting story, where estimates range from near zero to very substantial and the implausibly large. The variation across time and place is relevant because there is no reason to expect universally valid findings. Thus, even if Entorff and Kramarz's findings are accepted in full, there is little reason to expect that the valuation of computer skills in France during the 1980s can be a satisfactory basis for analysing the altogether different British labour market twenty years later. Similarly, Spitz-Oener (2007) finds that, revisiting similar but more recent German data to that which generated the 'pencils effect' rebuttal of the computer wage premium, the computer use premium remains robust while the pencils effect had disappeared. The findings in Britain generally indicate that there has been a positive pay premium, yet neither is its magnitude established (which pertains to the issue of whether computers have directly affected the pay distribution), nor whether there is a tendency for computer skills premia to decline as the supply becomes more widespread. Much of the literature in all countries has been handicapped by poor data, in which employees are recorded to be either computer users or non-users, rarely complemented by information on the type of usage, and normally lacking measures of the intensity or level of usage (and hence of the required skills). In most cases, few or no other generic skills are measured and controlled for. Occasionally, researchers have resorted to self-assessment of skills (Borland et al. (2004) and Liu (2004)), which can easily be compounded by personality traits.

Finally, the conclusion that ICT's impact on productivity is complementary with investments in organisational change (e.g. Crespi et al., 2006) is not reflected so far in these studies of computers and pay. Yet there is reason to expect such a connection, in that higher-level skills at managerial and professional levels will be associated with being able to bring about organisational change to generate efficient usages of ICT investments. Organisational changes, we know, have tended to be both skill-biased and effort biased (Caroli and van Reenen, 2002; Green 2004); and ICT investments interact in their impact on productivity with the proportion of graduates at industry level (Bloom et al. 2005). One might also expect the computer skill premium to be complementary with other skills associated with the ability to bring about organisational change.

The literature therefore leaves unsettled a number of issues about the potential role of computers in determining pay in Britain's labour market. This paper will address the questions:

i. As investment in information technologies has proceeded apace, what have been the changes in the prevalence of computer-users, and to the level and intensity of computer usage? Which groups have been gearing up the most to using computers at work?

ii. What are the best estimates of how much computer skills are affecting pay in Britain in recent years, and how is the premium changing over time as competence with IT gradually spreads across the population? Are computing skills becoming like driving skills: imperfect but ubiquitous, with little additional scarcity value in the labour market?

iii. Is there any evidence that computer skills are complementary with other scarce generic skills, especially those that might be expected to be associated with the ability to bring about efficient organisational change?

2. Data.

Consistent historical and recent data on the deployment of computer skills at work are available from a series of individual surveys that runs from the Social Change and Economic Life Initiative (SCELI) in 1986, through the Employment in Britain of 1992, and then the 1997, 2001 and 2006 Skills Surveys. The 1997 Skills Survey was designed in part to deliver some detailed knowledge about the importance of a wide range of activities carried out at work. These data were collected by adapting the methods of job analysis for the purposes of social survey. The outcome of this approach was that it enabled the measurement of the usage of several generic skills, including computing skills. The 2001 and 2006 Skills Surveys are partial repeats of the questionnaire used in 1997, and in particular provide a consistent series of data on computing and the other generic skills.

These surveys targeted the population of 20 to 60 year-olds in employment (or, in the case of 2006, ages 20 to 65), using clustered random sampling methods. Achieved samples were all closely nationally representative as judged by comparison with Labour Force Survey benchmarks.[1] In addition, the 2006 survey included over-sampling surveys of Wales, Scotland and the East Midlands, and for the first time included a sample of people in employment in Northern Ireland. This paper focuses only on employees in Britain, and in the trend analyses just on those aged 20 to 60. All analyses incorporate both a design weight that takes account of clustering, household size, and oversampling, and a non-response weight to take account of a slightly higher non-response rate from males than from females. Data was collected using face-to-face interviews, conducted in people's homes. Full details of methods can be obtained from Gallie et al. (1998), Ashton et al. (1999), and Felstead et al. (2002; 2007).

[1] Green et al. (2000) show that the sampling methods used in SCELI yielded a near-representative sample for Britain, while the other four surveys were representative by design.

The general principle which underpins the ‘job requirements’ approach to skills analysis is the strategy of asking respondents consistent questions about the activities involved in their jobs. Indicators of these activities are then treated as measures of the skills being deployed. The utilisation of computer skills is measured in a number of ways. The simplest indicator is ‘Participation’ which derives from the (binary) answers to the question ‘does your own job involve use of computerised or automated equipment?’. Though this indicator fails to capture the importance and level of sophistication with which computers are used, the data are available on a consistent basis back to 1986. A second indicator is derived from a question designed to elucidate whether and how far computing skills are central to the job: ‘how important is using a computer, 'PC', or other types of computerised equipment?’. We refer to this as the ‘centrality’ of computer use. Answers were on a 5-point scale ranging from ‘not at all important/does not apply’ to ‘essential’. A third indicator captures the level at which computers are used. Respondents are asked to place the way they use computers on one of four levels, ranging from ‘straightforward’ to ‘advanced’, with examples being given to anchor each level. Fourth, respondents were also asked, from 2001 onwards, to report the centrality of internet usage. Fifth, respondents reported the proportion of employees in their workplace that used computers.

The Skills Surveys also measure several other generic skills that are used in many different kinds of jobs, in a consistent way from 1997 through 2006. Exploratory factor analyses were used to guide reduction of over 40 items, each measured on a 5-point importance scale, to 12 theoretically-based skills domain indicators. Rather than compute factor scores, items were grouped as suggested by the factor analysis, and additive indices were generated to create the variables measuring the utilisation of skill in each of the 12 domains. Additive indices have the benefit of being more easily interpreted in relation to the original item scales, while factor scores contain weighted contributions for all 40 items, albeit with only small weights from the large majority of items not included in each skill domain (Felstead et al., 2007). In this paper we focus in particular on a skill domain - ‘influence skills’ - that we believe is likely to be associated with the successful and effective introduction and deployment of ICT in workplaces. As argued in studies of ICT’s impact on productivity, the effect of ICT is likely to be greatest when combined with good work organisation. It follows that computing skills should be complementary with other generic skills in their effects on productivity. In particular, we hypothesise that this requires employees both to assess the potential benefits to be gained from successful ICT use and to be able to persuade and influence and educate others in the workplace. Influence skills in our data are derived from the items capturing the importance of: persuading or influencing others; instructing, training or teaching people; making speeches or presentations; writing long reports; analysing complex problems in depth; and planning the activities of others.[2] These items have an acceptable Cronbach's alpha statistic of 0.84. We standardise the resulting index, which we simply term Influence Skills[3], so that the range is from 0 to 4, where 4 would result if the response to all items was 'essential', 0 if all responses were 'not at all important/does not apply'.[4]

3. The growth and distribution of computing and influence skills in Britain.

Figure 1 and Table 1 show the remarkable invasion of computers into the British workplace over the last 20 years. Taking first the simple measure of 'participation', the proportion of employees using computers by this definition has nearly doubled since 1986, and appears to be heading towards a plateau of just over three quarters of the employee workforce. Over the same period there was a similar growing proportion of computer-intensive workplaces where at least half the employees are reported to be using computers or automated equipment.

The mere use of a computer, however, is a very loose indication of the skills being deployed, since computers can vary greatly in their importance for the job and in the level at which they are used. Figure 1 also plots the 'centrality' of computer use to jobs. The proportion of those answering at the top of the scale ('essential') rose from 33% to 49% between 1997 and 2006. In addition to computers being 'essential' for half of British employees, another quarter of employees rated them as 'fairly important' or 'very important' in 2006.

Our figures for 2006 can be compared with estimates from the recent 'Community Survey on ICT usage in households and by individuals', according to

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[2] In addition to influence skills, the other skill domains are labelled: literacy, number, physical, technical know-how, planning, client communication, horizontal communication, problem-solving, checking, aesthetic, emotional.

[3] We use title case when we wish to refer specifically to the index, and lower case when we refer to the underlying concept of influence skills.

[4] Influence Skills should be distinguished here from autonomy (which encompasses influence over one's own work). We also include autonomy as a control in the regressions below.

which 74% of employees use computers, internet or e-commerce (Demunter, 2005), comparable with the Skills Survey figure for participation. Moreover, the Community survey documents that 49% of employed persons in the UK were using computers 'in their normal routine' (Demunter, 2006). This UK figure, which is close to the European Union average[5], is comparable with the Skills Survey figure for centrality.

The expanded computer use might have been expected to dilute usage, with progressively lower-level users adopting the technology at easier levels. The third series shows that this did not happen. The proportion of employees who use computers at a 'high' level – either 'complex' or 'advanced' usage – rose from 16% to 23% over 1997 to 2006. Taken as a proportion of computer-users only, the increase was from 24% in 1997 to 28% in 2006. Examples of 'complex' use were: using a computer for analysing information or design, including use of computer aided design or statistical analysis packages; an example of 'advanced' use was using computer syntax and/or formulae for programming. Through this time, therefore, not only were more and more employees being joined up to the digital revolution, the preponderance were progressively being called on to exercise higher-level computing skills. Finally, Figure 1 also documents the very rapid recent expansion of internet usage at work. The proportion of jobs where internet usage was essential rose from 14% to 28% just in the short period from 2001 to 2006.

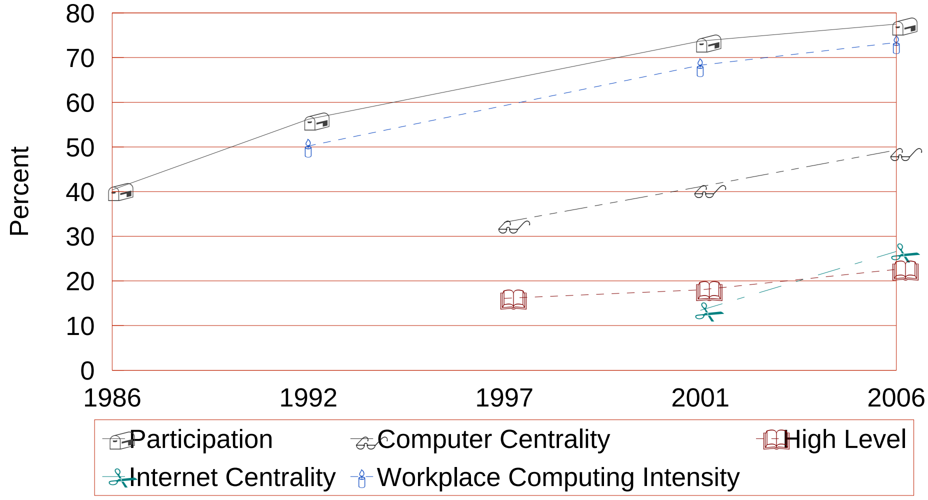
Table 1 shows something of how computing skills are distributed among the population of employees in Britain. There are relatively small differences between men and women as regards the participation in computer use, though in the past participation used to be greater for women. Now, computing is regarded as 'essential' in 48% and 51% of the jobs done by men and women respectively. There is a much larger difference, however, when it comes to the level of computer usage: the proportions using computers at 'complex' or 'advanced' levels is 28% for men, compared with 17% for women, a differential that has been maintained throughout the decade of rapid ICT expansion.[6] As expected, younger employees are more likely to have computer skills than older workers, though the differences in participation between young and old have narrowed in recent years.

[5] Unfortunately the EU surveys are only of recent vintage and do not provide a historical perspective.
[6] There are especially sharp differences among women according to their status as part-time or full-time workers (Felstead et al., 2007).

If computer skills affect labour market prospects, it is of some interest to see how those from different educational background vary in their use of computing skills. The differences are unsurprising but stark. In terms of participation, the figure for those with degrees is 71%, compared with just 20% for those holding no qualifications, a gap of 51 percentage points. The absolute differences have been widening over the decade: back in 1997 the equivalent gap was only 40 percentage points. There is also a very large difference in 2006 between educational groups regarding the use of computers at 'high' levels: 42% for graduates, compared for example with 19% for those with just A level or equivalent.

Table 1 also documents the changes and the distribution of influence skills. Between 1997 and 2001 the Influence Skills index rose from 1.81 to 2.06, a rise of about one quarter of its 1997 standard deviation. This rise is statistically significant (p=0.000). An alternative way of describing this change (not shown in the table) is to compute the proportion of jobs for which Influence Skills is at least 3, (which is equivalent to the items being on average at least 'very important' in the job). This proportion rose from 17% in 1997 to 23% in 2006. The increase is especially high among managers (34% to 44%), and among associate professional occupations (23% to 31%). Thus, influence skills, which we hypothesise to be complementary with the skills needed for the efficient deployment of ICT in workplaces, are rising, and not just because of the generally increasing prevalence of managers and professionals in workplaces. Finally, Table 1 also documents that influence skills are, unsurprisingly, very much more widely deployed in the jobs of the highly educated compared with those in lower educational groups; though note that influence skills are growing even in the lower educated groups.

Figure 1 Computer Use 1986 to 2006



Notes: 'Participation' means use of computerised or automated equipment; 'Workplace Computing Intensity' is % of workplaces where at least a half of employees use computers; 'Centrality' is % of jobs where use of a pc or other type of computerised equipment is 'essential' (5-pt scale 'essential' to 'not at all important/does not apply'); 'High Level' is % of jobs where computers are used at 'complex' or 'advanced' levels (see text); 'Internet Centrality' is % of jobs where internet use is 'essential' (5-pt scale 'essential' to 'not at all important/does not apply').

Table 1 Computing and Influence Skills, 1997-2006.

		'Centrality' of Computing*	'Level' of Computing**	Influence Skills***
All Employees	1997	33.1	16.1	1.815
	2001	41.1	18.0	1.917
	2006	49.3	22.6	2.062
Men	1997	29.9	19.9	1.91
	2001	40.0	22.4	2.005
	2006	47.6	28.2	2.106
Women	1997	36.7	11.8	1.71
	2001	42.4	12.9	1.817
	2006	51.1	16.8	2.017
Age 20-40	1997	35.1	17.9	1.786
	2001	44.2	21.5	1.942
	2006	50.8	26.2	2.055
Age 41-60	1997	30.4	13.6	1.856
	2001	37.5	13.8	1.888
	2006	47.6	18.7	2.071
Education Level				
No qualifications	1997	13.5	2.5	1.19
	2001	15.4	4.6	1.322
	2006	20.0	3.8	1.412
NVQ1 or equivalent	1997	22.0	8.5	1.523
	2001	25.7	4.5	1.501
	2006	30.9	10.7	1.546
GCSE Grade C or equivalent	1997	34.8	10.2	1.643
	2001	42.1	13.3	1.677
	2006	47.4	13.5	1.807
A level or equivalent	1997	38.3	19.9	1.879
	2001	41.4	19.5	1.882
	2006	42.9	18.7	1.998
Professional or Vocational Degree	1997	37.6	26.7	2.458
	2001	48.7	24.5	2.334
	2006	61.6	31.0	2.475
Bachelor's Degree Level or above.	1997	53.3	38.4	2.585
	2001	60.8	33.7	2.584
	2006	70.5	42.4	2.605

Notes for Table 1:
Figures are for employees in England, Wales and Scotland, aged 20 to 60; excludes those working in private households or extra-territorial organisations.
*Percentage reporting use of PC or other types of computerised equipment to be 'essential' in their job.
** Percentage reporting that they use computers at a 'complex' or 'advanced' level. Examples of 'complex' use were: using a computer for analysing information or design, including use of computer aided design or statistical analysis packages; an example of 'advanced' use was using computer syntax and/or formulae for programming.
*** Index derived from six closely correlated items; see text.

4. The returns to computing and influence skills.

Section 3 has documented that the last decade has been a period of rapid deployment of computer skills in workplaces, and has also noted a more modest but still significant increase in the use of influence skills. Moreover, the deployment of both types of skill has been found to be strongly positively related to education level. With such a profound change in workplaces, along with the obvious costs and constraints associated with the acquisition of these skills, it would not be surprising if bottlenecks occur and that the possession of computing skills (and possibly influence skills) acquire scarcity quasi-rents and/or permanent returns in the labour market.

In this section, the aim is to investigate the effect that computer skills have on hourly pay, over and above the normal returns to the education that may have contributed to acquiring computing skills. We do this by estimating standard earnings equations including schooling and a quadratic term in work experience, and other conventional controls, and supplementing these with our measures of computing skills. We also investigate whether, and if so how much, any impact of computing skills is effected through the simultaneous deployment of influence skills, as hypothesised above. We do this by interacting the Influence Skills index with our measures of computing skills.

Tables 2 and 3 show our findings in respect of men and women based on the 2006 Skills Survey data. We restrict the analysis to employees only. In each case column (1) is a benchmark earnings regression giving returns to schooling of approximately 6% and 8% for males and females respectively.

Table 2

The Impact of Computing and Influence Skills on Hourly Pay of Men, 2006.

	(1) OLS	(2) OLS	(3) IV	(4) OLS	(5) OLS
Years of Education	0.061 (0.005)**	0.044 (0.004)**	0.038 (0.007)**	0.035 (0.004)**	0.030 (0.004)**
Work Experience (yrs)	0.041 (0.003)**	0.037 (0.003)**	0.034 (0.006)**	0.029 (0.003)**	0.029 (0.003)**
Work Experience Squared/100	-0.068 (0.007)**	-0.059 (0.006)**	-0.053 (0.010)**	-0.045 (0.006)**	-0.047 (0.006)**
Computing Skills		0.146 (0.008)**	0.187 (0.034)**	0.063 (0.017)**	0.026 (0.018)
Influence Skills				0.011 (0.021)	0.032 (0.025)
(Computing Skills) times (Influence Skills)				0.018 (0.009)*	0.013 (0.009)
Proportion (pr) of workers using computers in establishment:					
¼ <= pr <= ¾				0.024 (0.043)	0.038 (0.042)
pr > ¾				-0.102 (0.054)+	-0.096 (0.051)+
(Influence Skills) times (¼ <= pr <= ¾)				0.006 (0.025)	-0.000 (0.023)
(Influence Skills) times (pr > ¾)				0.094 (0.029)**	0.084 (0.027)**
OTHER SKILLS INDICES	NO	NO	NO	NO	YES
Observations	2641	2641	1534	2641	2641
R-squared	0.31	0.42		0.47	0.51

Notes:
Robust standard errors in parentheses; + significant at 10%; * significant at 5%; ** significant at 1%. Weighted regressions. The dependent variable is log hourly pay. All regressions contain standard controls for workplace size, part-time status, public/private sector, permanent/temporary contract status, whether male or female dominated occupation, industry and region. Column (4) includes also 12 further generic skills indicators including a measure of autonomy computed from the job requirements data (see Felstead et al., 2007).

Column (3) is run for those who were in the same job either 3, 4 or 5 years previously. Instruments used for IV estimates: whether in last 5 years workplace has introduced new computing equipment, whether introduced new communications technology equipment, whether introduced other new equipment; and whether workplace has downsized.

Anderson canonical correlation LR statistic to test for underidentification test: 153.172, $\chi^2(4)$ (P-value = 0.0000); Cragg-Donald F statistic for weak identification: 39.220; Hansen J test statistic for overidentification of all instruments: 0.310, χ^2 (3) P-value = 0.9581.

Table 3

The Impact of Computing and Influence Skills on Hourly Pay of Women, 2006.

	(1) OLS	(2) OLS	(3) IV	(4) OLS	(5) OLS
Years of Education	0.076 (0.004)**	0.064 (0.004)**	0.071 (0.006)**	0.048 (0.004)**	0.043 (0.004)**
Work Experience (yrs)	0.029 (0.003)**	0.027 (0.003)**	0.028 (0.004)**	0.020 (0.002)**	0.020 (0.002)**
Work Experience Squared /100	-0.046 (0.005)**	-0.043 (0.005)**	-0.044 (0.007)**	-0.029 (0.005)**	-0.030 (0.005)**
Computing Skills		0.109 (0.008)**	0.098 (0.035)**	0.032 (0.014)*	0.018 (0.015)
Influence Skills				0.018 (0.018)	0.040 (0.023)+
(Computing Skills) times (Influence Skills)				0.021 (0.008)*	0.021 (0.008)*
Proportion (pr) of workers using computers in establishment:					
¼ <= pr <= ¾				-0.006 (0.041)	0.003 (0.040)
pr > ¾				0.009 (0.042)	0.010 (0.042)
(Influence Skills) times (¼ <= pr <=¾)				0.021 (0.023)	0.018 (0.023)
(Influence Skills) times (pr > ¾)				0.041 (0.024)+	0.038 (0.023)
OTHER SKILLS INDICES	NO	NO	NO	NO	YES
Observations	2852	2852	1652	2852	2852
R-squared	0.41	0.47		0.54	0.56

Notes: See Table 1.

For column (3) Anderson canonical correlation LR statistic to test for underidentification test: 141.106, $\chi^2(4)$ (P-value = 0.0000); Cragg-Donald F statistic for weak identification: 35.935; Hansen J test statistic for overidentification of all instruments: 2.004, χ^2 (3) P-value = 0.5716.

Column (2) introduces computing skills. For this purpose we have averaged the indices of computing centrality and of computing level to form a single index (termed simply 'Computing Skills'[7]) that ranges from 0 to 4.[8] Justification for this procedure is that the two constituent indices, though conceptually distinct, are closely

[7] Henceforth, we use title case when we wish to refer specifically to the index, and lower case when we refer to the underlying concept of computer skill.

[8] Thus, 4 indicates computers are essential and used at an advanced level, while at the other extreme 0 indicates computers are not used at all in the job.

correlated (ρ=0.78), and can each be seen as proxies for a latent variable measuring the computing skills needed to perform a job.[9] A one-unit change in the Computing Skills index amounts to 89% and 95% of the standard deviations within the male and female samples respectively. As can be seen, there is a substantial and significant return to Computer Skills, the estimated coefficient for the impact of Computer Skills on log pay being 0.146. This implies, for example, that a job requiring use of computer-aided design skills would pay 7.9% (= 0.5 x 100 x $e^{0.146}$-1) more than a job requiring the use of word-processing or spreadsheet skills, assuming that computers were equally important in the two jobs, and that the job-holders had the same amount of education and experience.

It is quite possible, however, that this estimate is upward-biased through omission of other skills domains also not captured fully by the controls for education and work experience. One way to attempt to obtain an unbiased estimate is through instrumenting Computing Skills. We utilise for this purpose variables capturing whether there have been recent changes in the workplace. Four relevant variables are included, each as 0/1 dummies: whether in the last 5 years the workplace has introduced new computing equipment, whether it has introduced new communications technology equipment, whether it has introduced other new equipment, and whether the number of employees has been reduced. We maintain that it is plausible that these variables may affect whether computers are being used in a job, but that they would not necessarily have significant direct effects on pay. Both for men and for women, these instruments pass the Hansen J test which allows us to accept the hypothesis that the variables do not directly affect pay; the instruments also strongly identify the deployment of computing skills. For the purpose of the IV estimations, the samples are of necessity restricted to those employees who had been in the same job for the previous 5 years.[10] As can be seen in column (3) of both tables, the estimated impact of computing skills is a little higher than the OLS estimate, in the case of males, and only marginally lower in the case of females.[11] There is, therefore, some support for the view that computing skills are earning a true independent return in the labour market.

[9] In practice, treating the indices separately did not lead to better-performing earnings functions.
[10] If not in work 5 years previously, respondents reported about the last 4 years or, successively, 3 years.
[11] For direct comparability, the OLS estimates for the identical sample used in the IV estimates were 0.144 (0.010) for males and 0.114 (0.010) for females.

In column (4) we investigate whether part of the impact of computing skills is complementary with influence skills which, as hypothesised, may improve the effective use of computers in jobs. We also include our indicator of the intensiveness of computer use in the workplace as a whole. The hypothesis here is that influence skills may interact both with individual computer use and with workplace computer intensity. Our estimates show that the effect of a unit increase in Computer Skills *per se* on log pay is much reduced though still significant (at 0.063 for men, 0.032 for women). Influence Skills on its own appears to have no significant association with pay. There is, however, a significant interactive effect from Computer Skills and Influence Skills for both men and women, supporting our hypothesis of complementarity. At the mean of Influence Skills, the additional interactive effect on log pay of a unit rise in Computing Skills is 0.037 for men and 0.042 for women.

Moreover, influence skills are complementary also with workplace computing intensity: for both men and women, the Influence Skills index raises pay by an additional significant amount in high-computer-intensive workplaces (where at least three-quarters of employees are working with computers or automated equipment), but not in workplaces that are less intensive in computer use. A one point increase in Influence Skills[12] yields an additional 10% pay premium for men, and 4% for women, in the high-computer-intensive workplaces.

In column (5) we examine how far these estimates are robust to the inclusion of the twelve other generic skills indicators available in the Skills survey data. This exercise pursues further the possibility, already examined in one way through the IV estimates of column (3), that the estimates of computing skills are biased by the omission of other correlated skills which are rewarded in their own right and may have little to do with technology. As can be seen, inclusion of very many skills domains reduces the point estimate of most coefficients including that of computing skills on its own which becomes statistically insignificant. At the mean value of Influence Skills, the combined direct and interactive effect on pay of a one unit rise in computing skills is significant (p=0.000) and amounts to 5.3% for men and 6.0% for women. Moreover, for women there remains a substantive and significant interaction

[12] Equivalent to 98% and 96% of the standard deviation for men and for women respectively.

with Influence Skills. In the case of men, there is an additional significant interactive effect from Influence Skills in high-computer-intensive workplaces.[13]

The next question we wished to investigate is whether the computing skills premium has been changing over time. A rising premium would be an indication of scarcity in the face of the rapidly rising deployment of computing skills documented in Section 3. On the other hand, one might expect that as familiarity with computers spreads through the population the link with pay would be reduced.

Tables 4 and 5 present estimates for men and women of the returns to computing and influence on a consistent basis in each of the three Skills Survey years: 1997, 2001 and 2006. Each regression includes all available controls, including those of multiple other generic skills domains. Workplace computer intensity, however, is excluded as this question was not asked in 1997.

Both tables show an increasing extent to which Computer Skills and Influence Skills interact to affect pay. While in 2006 the interaction is substantial and significant (as found in Tables 2 and 3) the estimated coefficient is smaller and insignificant in 2001, and in 1997 carries a small negative but insignificant estimate. In parallel, the estimates of the direct effects of Computer Skills and Influence Skills decrease over time. On average, the overall impact of Computer Skills on pay has increased over the period. Evaluated at the mean level of Influence Skills for the whole decade (2.03 for men, 1.89 for women) the direct and interactive effect of a unit increase in Computing Skills on pay is estimated to have risen from 5.0% in 1997 to 7.2% in 2006 for men, and from 4.4% in 1997 to 7.7% in 2006 for women. For those men and women in jobs with above average Influence Skills the Computer Skills premium rose faster than for those in jobs that use below-average Influence Skills.

It thus transpires that the interaction between computing and influence skills is a very recent phenomenon. There is indeed some evidence that the rapid diffusion of ICT in British workplaces over the last decade is placing an increasing premium on those who have been able to acquire the skills to utilise the new technologies; but it is predominantly those jobs that also deploy high levels of influence skills (where, we

[13] It could be argued that computing skills might also complement other generic skills. We have checked that the pattern of results shown here does not alter when computing skills are interacted with all other generic skills indicators and with autonomy. Moreover, the large majority of these other interactions are statistically insignificant; we prefer to exclude them from the analyses here, rather than just include the few that turn out ad hoc to be significant.

have reasoned, the technologies are likely to be used more effectively) that are now being rewarded with a scarcity premium for computing skills.

Table 4 Returns to Computing and Influence Skills Over Time for Men

	1997	2001	2006
Computing Skills	0.077 (0.022)**	0.038 (0.017)*	0.021 (0.015)
Influence Skills	0.129 (0.030)**	0.121 (0.027)**	0.077 (0.022)**
(Computing Skills) times (Influence Skills)	-0.013 (0.010)	0.013 (0.009)	0.025 (0.007)**
Observations	978	1811	2525
R-squared	0.49	0.45	0.49

Notes: Robust standard errors in parentheses; + significant at 10%; * significant at 5%; ** significant at 1%. Weighted regressions; all years refer to population of GB aged 20-60.

The dependent variable is log hourly pay. All regressions include schooling and a quadratic in work experience and contain standard controls for workplace size, part-time status, public/private sector, permanent/temporary contract status, whether male or female dominated occupation, industry, region and 10 further generic skills indicators including a measure of autonomy computed from the job requirements data (see Felstead et al., 2007).

Table 5 Returns to Computing and Influence Skills Over Time for Women

	1997	2001	2006
Computing Skills	0.050 (0.017)**	0.053 (0.015)**	0.027 (0.014)+
Influence Skills	0.125 (0.025)**	0.119 (0.021)**	0.085 (0.022)**
(Computing Skills) times (Influence Skills)	-0.003 (0.008)	0.003 (0.007)	0.026 (0.007)**
Observations	967	1816	2770
R-squared	0.60	0.50	0.53

Notes: see Table 4.

Conclusion

If all computers did to jobs were to put keyboards under the fingers of clever people who previously grasped pens and were always highly paid, there would be no need to worry about any effects of scarce computer skills on inequality. If, however, computer skills are costly to acquire but the expense is least, and access greatest, for better-educated and more advantaged groups in society, then the computer revolution can be seen as materially affecting the wage structure and as a potential source of greater inequality.

Our findings are consistent with the view that the diffusion of computing technology through the British economy is having notable effects on the labour market. There has been a remarkable rise in the proportions of jobs participating in the use of computers, to the extent that in 2006 three in four jobs entailed job-holders using computers, while for two in four jobs computer use was 'essential'. At the same time, the level of computer use, far from being diluted by an influx of users facing only basic skills requirements, has risen. Computing skills requirements are, unsurprisingly, much higher for those with more education behind them. Moreover, there is no sign of any narrowing in the computer skills gap, and indeed the gap appears to be widening. For example, the 'centrality' of computing – the proportions for whom computers are essential – increased over 1997 to 2006 by 17 percentage points for those educated to degree level, but only by 6 percentage points for those with no qualifications.

We have found that computing skills have a significant impact on pay but, in 2006, much of this effect is interactive with influence skills which we have argued to be complementary with computing skills in their effects on performance. Influence skills, which the data show cluster together in jobs, involve persuading or influencing others, instructing, training or teaching people, making speeches or presentations, writing long reports, analysing complex problems in depth, and planning the activities of others. Our best estimate of the average combined direct and interactive effect of a unit increase in the Computing Skills index (which ranges from 0 to 4) is that this raises pay, after allowing for many other skills and conventional controls, by 5.3% and 6.0% for men and women respectively. To place this in the context of a concrete example, a job where a computer was described as 'very important' and was used for computer-aided design, would pay 16% more than an otherwise identical job that required no computer use at any level. However, the effects are greater than that for those people in jobs with above-average Influence Skills requirements. Moreover, for those people with average Influence Skills there is an additional boost to pay in establishments where at least three quarters of workers are working with computers, compared to establishments where no one uses computers: this boost amounts to an estimated 19.2% for men and 7.9% for women, though the latter is not quite significant at conventional levels. All these estimates are arrived at after allowing for a large number of other generic skills and other conventional controls, which makes them more robust to the critique that they are overestimates because they might suffer from omitted skill bias. Our IV estimates also show only small differences from the OLS estimates. Nevertheless, it remains possible that our computer use measures are proxying other unobserved real pay-determining factors which would not be affected by computer skills training.

The direct and interactive effect of Computer Skills and Influence Skills has risen somewhat over the decade, indicating increased scarcity. It is notable, however, that in earlier years the impact of computing skills on pay was more direct and depended far less or not at all on the use of influence skills. It is only recently that the complementarity has become evident. A possible interpretation one might put upon this late manifestation of complementarity is that there is a long and uncertain lag in the process through which managers and others learn how to deploy ICT technologies effectively, and that this learning process occurs at the same time as the technology is developing and new applications are conceived.[14] Whereas, a decade ago, computer skills were valuable generally, in recent years computer skills have become especially productive in jobs where influence skills are also important, and less so in jobs that entail little use of influence skills and where computer applications have become more routine. Whatever the explanation, our findings indicate that the complementarity is only now beginning to emerge after a decade of high investment.

The implied increased scarcity of computing skills, evident in our findings, provides general support for policies to broaden the stock of computing skills in the population; the findings also reinforce the need to ensure adequate supplies of people with what we have termed ‘influence skills’.

Showing that computing skills affect pay is a necessary but insufficient foundation for any argument that ICT raises inequality. Our findings do *not* establish,

[14] Changing applications on the internet are documented in Felstead et al. (2007: 101).

one way or another, that the rise of ICT has had a notable effect on inequality compared to some hypothetical counterfactual alternative world. As can be observed from Tables 2 and 3, part of the return to education is tied up with the impact of the higher computing and influence skills associated with it – the estimated return coming down from .061 to .035 for men, and from .076 to .048 for women, once both Computing skills and Influence skills are allowed for. In 1997, however, the effect on the schooling coefficient of including Computing and Influence Skills is of similar magnitude to the effect in 2006 – suggesting that, despite the increasing premium on computing skills and its concentration in high education groups, any impact on changes in the overall pay/education structure is small. However, since differential schooling is only part of the explanation for wage inequality, a thorough investigation of the impact of computing on wage inequality would need to be much more comprehensive, and has not been part of our objectives in this paper. Since wage inequality began to increase in the late 1970s, before the computer revolution became widespread in the workplace, it seems unlikely that computers on their own could ever be a major part of the explanation of past rises in inequality. Nevertheless, the rising importance of computers, and the increasing concentration on higher education groups which we have documented here, implies that computing skills could, if these trends were to persist and the digital skills gap to widen still further, play an increasing role in accounting for pay dispersion in the coming years.[15]

[15] This paper has been narrowly materialistic in focussing on the effects of computers on pay. The impact on other variables related to worker well-being, including job autonomy and job satisfaction, are to be the focus of subsequent research.

Annex: Descriptive Statistics

Table A1

Means of Dependent and Independent Variables in Table 2 and Table 3.

	Males	Females
Log Hourly Pay	2.39	2.16
Years of Education	12.98	12.93
Work Experience (yrs)	23.82	23.68
Work Experience/100	7.21	7.05
Computing Skills	2.09	2.09
Influence Skills	2.08	2.00
Proportion (pr) of workers using computers in establishment:		
¼ <= pr <= ¾	0.25	0.22
pr > ¾	0.51	0.56

Table A2.

Means of Dependent and Independent Variables in Table 4 and 5

	Males			Females		
	1997	2001	2006	1997	2001	2006
Log Hourly Pay	1.97	2.18	2.39	1.71	1.93	2.17
Computing Skills	1.78	2.06	2.18	1.72	1.98	2.14
Influence Skills	1.93	2.00	2.10	1.71	1.81	2.02

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