

10. How computerization has changed the labour market: A review of the evidence and a new perspective*

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10.1 INTRODUCTION

The use of computer technology at work has increased dramatically over the past decades from about 20 per cent in the early 1980s to more than 70 per cent at the beginning of the new millennium. This increase in the adoption and use of new technology is likely to have changed the labour market in many dimensions.¹ With respect to wages it has been found that computer users earn substantially higher wages than non-users, with wage premiums up to levels as high as 20 per cent. It is however not clear whether this observed premium is a reflection of the returns to (computer) skills, the result of unobserved heterogeneity between computer users and non-users, or whether there are other sources underlying these wage differentials.² Computer technology is particularly used by the more highly educated workers, suggesting skill advantages play a crucial role in adjusting to and using new technologies. Hence, adoption of computer technology is easily connected to changes in the wage structure. On the other hand, looking at the present use of computer technology, it is hard to understand why more highly educated workers have an advantage in using for example a PC compared with less highly educated workers. Related to this observation is the

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issue of the trend towards skill upgrading over the past decades. Is it really true that skill upgrading is the result of differences in computer skills between workers? Investigations of patterns of computer use over the life cycle have been concerned with the notion that older workers might be less able to work with computer technology and end up being unemployed. However, figures suggest that the patterns of computer technology use over the life cycle have been surprisingly flat.

While most observers agree that computer technology has changed the workplace to a considerable extent, there is no consensus with regard to how this change has occurred. This chapter reviews the most important developments in the economic literature on the impact of computer technology on the labour market and provides a framework to understand how computer technology has changed the labour market by developing and making use of a threshold model of technology diffusion. The focus of the model is to explain wage differentials between computer users and non-users, the secular trend towards upgrading of skill requirements, and the wage developments over time experienced by many OECD countries. It demonstrates that wage differentials between computer users and non-users are consistent with the fact that computer technology is first introduced in high-wage jobs because of cost efficiency. This stands in sharp contrast with the view that computer use increases wages. In fact, it reverses the causality of the relationship between computer technology and wages. In addition, the framework reveals that skill upgrading in jobs where computer technology is introduced occurs because of a re-emphasis on non-routine job activities or tasks. It also shows that neither differences in computer skills nor skills complementary to using computer technology are needed to explain wage differentials between computer users and non-users and to explain skill upgrading. Finally, the framework predicts a changing wage structure over time, which is consistent with the changes in the wage structure in the OECD countries over the past decades.

The chapter is in five sections. Section 10.2 presents information about the extent of computer technology use at work in a number of countries and discusses the trends over time. It also describes the development of wages, and particularly wage differentials between computer users and non-users, over time and relates these observations to the adoption of computer technology. Section 10.3 reviews previous empirical studies and discusses the suggestive evidence presented in this body of empirical work. Section 10.4 presents a threshold model of technology diffusion to provide a new perspective on the computerization of the labour market in which the empirical evidence can be reconciled and consistently explained. Section 10.5 concludes.

10.2 TRENDS IN COMPUTER TECHNOLOGY USE AND WAGE DIFFERENTIALS

Table 10.1 summarizes the incidence of using computer technology for different categories of workers in Britain, Germany and the United States in the mid-1980s and late 1990s. Computer technology use in the mid-1980s is lower in Germany and Britain than in the United States. However, by 1997 the levels of computer use in Germany and Britain are higher. Differences in these figures might of course be the result of different wordings of the questions in the survey, but comparisons with other sources of information about computer technology usage suggest that such effects are likely to be of a small magnitude.³ The most important message from the numbers in the table is that although computer use at work is increasing over time, the patterns of use among various labour-market groups are very similar in

Table 10.1 Percentage of workers in age, educational level and gender categories using computer technology at work in Britain, Germany and the United States

	Britain		Germany		United States	
	1985	1997	1985	1997	1984	1997
All workers	19.3	69.2	19.3	56.2	24.3	52.5
Age:						
20–29	21.2	67.8	18.4	50.8	24.8	47.8
30–39	24.0	71.6	22.0	57.6	27.9	54.3
40–49	13.7	71.9	19.3	58.3	23.2	55.5
50–60	17.1	63.0	13.8	56.6	18.4	50.6
Educational level:						
< High school	12.0	40.2	4.3	23.8	5.1	12.6
High school	28.2	55.1	18.4	50.5	19.2	36.9
Some college	31.5	75.1	25.6	76.9	30.6	53.2
College or higher	45.9	95.5	33.6	87.6	42.4	71.2
Gender:						
Men	24.1	69.2	18.6	54.4	21.6	43.6
Women	14.9	69.1	21.0	60.5	29.6	55.6

Note: Data about computer technology use in Germany refer to the Länder of the former West Germany only. German data are taken from the *German Qualification and Career Survey*. Information about Britain stems from the *British Social Attitudes Survey* for 1985 and the *Skills Survey of the Employed British Workforce* for 1997. Data on computer use in the United States are based on the 1984 and 1997 October Supplements to the *Current Population Surveys*.

relative terms. Computers are predominantly used by the more highly educated, but there is also a considerable group of less highly educated workers whose jobs involve the use of computer technology. In contrast to what is often expected, the highest rate of computer technology use at work is not found in the youngest age group (20–29): workers in the age group 30–39 or 40–49 are the most frequent users of computer technology and the oldest group of workers does not seem to suffer to a large extent from the adoption and diffusion of computer technology.⁴ What is also interesting to observe is that women are generally more likely to use computer technology at work than men, especially in the United States.⁵

There have been many other authors who have investigated the use of computer technology for a number of different countries. Examples are Reilly (1995) who used the *General Segmentation Survey* for Canada; Asplund (1997) used the Finnish labour force survey; Entorf and Kramarz (1997) and Entorf et al. (1999) explored the French labour force survey; Miller and Mulvey (1997) applied the *Survey of Training and Education* in Australia; Oosterbeek (1997) used information from the *Brabant Survey* to study computer use in the Netherlands; and Sakellariou and Patrinos (2000) described computer technology use among higher education workers in Vietnam using the *Higher Education Tracer Study* in that country. All studies reported an increasing pattern of computer technology use over time. For the United Kingdom, Bell (1996) used a different data source called the *National Child Development Study* and Chennells and Van Reenen (1997) and Haskel and Heden (1999) applied different waves of the British *Workplace Industrial Relation Surveys* to assess computer use at work. The results are comparable to the ones we present for the United Kingdom in Table 10.1. Hamilton (1997) used the *High School and Beyond Survey* for the United States and found similar computer use figures to the ones presented in Table 10.1 using the *Current Population Surveys*.

The adoption of computer technology has coincided with relatively large changes in the wage structure, mainly increasing wage inequality since the early 1980s, in many OECD countries. These trends have been carefully documented by, for example, Katz and Murphy (1992), Freeman and Katz (1995), Gottschalk and Smeeding (1997), Autor et al. (1998), Berman et al. (1998), Gottschalk and Joyce (1998), Machin and Van Reenen (1998), Katz and Autor (1999), Hollanders and Ter Weel (2002) and Acemoglu (2003). Table 10.2 takes a more modest approach by simply presenting the log wage differentials between computer users and non-users for Germany and the United States, in the 1980s and 1990s. What is clear from these numbers is that the wage differential between computer users and non-users is substantial, accelerating from the 1980s to the 1990s and levelling off somewhat towards the late 1990s. These numbers are consistent with the

Table 10.2 *Log wage differentials between computer using and non-using workers in age, educational level and gender categories in Germany and the United States*

	Germany				United States			
	1979	1985	1992	1997	1984	1989	1993	1997
All workers	0.137	0.236	0.271	0.292	0.264	0.309	0.349	0.352
Age:								
20–29	0.121	0.102	0.068	0.113	0.194	0.203	0.215	0.210
30–39	0.133	0.183	0.230	0.239	0.262	0.301	0.329	0.331
40–49	0.235	0.321	0.330	0.350	0.286	0.323	0.362	0.366
50–60	0.138	0.343	0.372	0.363	0.299	0.380	0.315	0.457
Educational level:								
< High school	0.137	0.226	0.231	0.220	0.224	0.270	0.307	0.230
High school	0.098	0.166	0.161	0.176	0.149	0.137	0.179	0.178
Some college	0.159	0.217	0.220	0.244	0.187	0.193	0.219	0.193
College or higher	0.041	0.133	0.162	0.217	0.164	0.206	0.234	0.225
Gender:								
Men	0.161	0.264	0.294	0.316	0.322	0.383	0.417	0.411
Women	0.142	0.191	0.226	0.280	0.284	0.318	0.353	0.364

Note: Data about computer technology use in Germany refer to the Länder of the former West Germany only. For Germany we use the *Qualification and Career Survey* of the German Federal Institute for Vocational Training (BIBB) and the Federal Employment Service (IAB). Data on computer use and wages in the United States are based on the 1984, 1989, 1993 and 1997 October Supplements to the *Current Population Surveys*.

evidence presented in the recent literature and suggestive to linking rising wage inequality to the computerization of the labour markets. The same trends seem to hold for all groups considered and the patterns are strikingly similar for Germany and the United States, despite the fact that the labour markets in these countries are often seen as examples of a highly institutional labour market and a labour market in which wages are determined by demand and supply. The German labour market structure would induce less wage dispersion among workers, which would be translated in a lower wage differential between those who use computer technology at work and those who do not. Apparently the wage differentials between computer users and non-users originate from other sources.

The figures presented in Tables 10.1 and 10.2 suggest that computer use is higher among more highly educated workers and is associated with higher

wages. In the next section we review the most prominent approaches to explain the relationship between wages and computer technology use.

10.3 A REVIEW OF THE EVIDENCE

Different authors have used different data sources to assess the impact of computerization on labour-market outcomes. We distinguish three different levels of aggregation by separately discussing papers that have applied individual level data and firm data and studies that have used data at the occupational or industrial level.

10.3.1 Individual Level Data

An important contribution to the debate concerning the effects of computer technology on wages has been made by Krueger (1993). His initial approach is to augment a standard cross-sectional earnings function to include a dummy variable indicating whether an individual i uses a computer at work:

$$\ln W_i = \alpha + \beta_i X_i + \gamma_i C_i + \varepsilon_i, \quad (10.1)$$

where C_i represents a dummy variable that equals one if individual i uses computer technology at work, and zero otherwise; $\ln W_i$ is the log of the hourly wage of worker i ; X_i represents a vector of observed characteristics; and α is the intercept.

Table 10.3 reports the coefficients of estimating equation (10.1) for the United States using the October Supplements to the 1984, 1989, 1993 and 1997 *Current Population Surveys*. Inclusion of several covariates in the wage equation suggests that computer users earn substantially higher wages than non-users and that the coefficient is relatively stable over time, ranging from 15.5 to 21.3 per cent. The studies for other countries mentioned in the previous section obtain generally similar results. Inclusion of only a dummy variable for using a computer at work leads to wage differentials ranging from 30.2 per cent in 1984 to 42.2 per cent in 1997. Similar wage differentials between computer users and non-users are obtained for the German and British data shown in the previous section.

Although it seems clear that computer users earn more than non-users, the figures presented in Tables 10.1 and 10.2 suggest that it is important to understand the effect of computer use on the relationship between earnings and education. A rather simple but straightforward test is to examine equation (10.1) first without computer use and then comparing these coefficients

Table 10.3 OLS regression estimates of the effects of computer technology use on pay in the United States, 1984–1997 (dependent variable: ln hourly wage (standard errors in brackets))

	1984	1989	1993	1997
Uses computer technology	.145 (.009)*	.153 (.009)*	.150 (.009)*	.144 (.010)*
Years of education	.058 (.002)*	.070 (.002)*	.070 (.002)*	.072 (.002)*
Experience	.026 (.001)*	.025 (.001)*	.027 (.001)*	.032 (.002)*
Experience squared/100	-.043 (.003)*	-.039 (.003)*	-.045 (.003)*	-.059 (.004)*
Black	-.090 (.011)*	-.087 (.011)*	-.066 (.011)*	-.076 (.012)*
Part-time job	-.212 (.010)*	-.150 (.011)*	-.188 (.010)*	-.160 (.012)*
Female	-.189 (.013)*	-.197 (.013)*	-.132 (.013)*	-.173 (.015)*
Married	.134 (.012)*	.142 (.012)*	.151 (.012)*	.123 (.013)*
Union member	.244 (.010)*	.224 (.010)*	.238 (.011)*	.201 (.013)*
Occupational dummies	Yes	Yes	Yes	Yes
Industry dummies	Yes	Yes	Yes	Yes
Regional dummies	Yes	Yes	Yes	Yes
Adjusted R ²	.409	.412	.417	.381

Note: * is significant at the 5 per cent level. All data are taken from the October Supplements to the *Current Population Survey* in the relevant years. The regression equation also included dummies for living in a small or medium-sized area and female*married.

with the ones reported in Table 10.2. In doing so, it turns out that the returns to a year of education without inclusion of the computer use dummy variable are 0.076 (0.001) in 1984, 0.091 (0.002) in 1989, 0.092 (0.001) in 1993 and 0.092 (0.001) in 1997 (standard errors in brackets). In other words, the rate of return to education increases by 1.5 percentage points between 1984 and 1989 if the computer dummy is excluded from the regression equation. If for 1984–1989 the computer dummy is included, the return to education increases by 1.1 percentage points. This implies that almost 30 per cent of the increase in the return to education can be attributed to the rise in computer use over the period 1984–1989. The validity of such an exercise is doubtful because for the other years in the sample the returns to education remain stable while the use of computers increases. In particular, this argument poses two problems. First, if computer technology increases the demand for skilled workers, this can raise the wages of all

skilled workers relative to unskilled workers, regardless of whether they actually use computer technology at work. Second, if something else changes the demand for skilled workers, it may also change the relationship between education and computer use. Hence, controlling for computer use might lead to attributing wages effects to computer use, even if the actual force were something else.

An alternative way to analyse the differentials in computer use by different educational groups is to add a (computer use * years of education) dummy. If the coefficient is positive it indicates that more highly educated workers gain more from computer technology use than less highly educated workers. However, the coefficients for this variable are all insignificant at the 5 per cent level. The coefficients are (standard error) 0.001 (0.001) for 1984, 0.006 (0.003) for 1989, 0.002 (0.002) for 1993 and -0.003 (0.003) for 1997. These results, although drawn from a simple framework, suggest that more highly educated workers do not seem to benefit more – in terms of wages – from computer technology use than less highly educated workers.

Krueger (1993) has analysed the returns to various uses of computers included in the CPS for the United States in 1989. He runs a wage regression including the usual suspects and the following specific tasks (coefficients and standard errors in brackets): word processing (.017 (.012)), bookkeeping (-0.058 (0.013)), computer-assisted design (0.026 (0.020)), electronic mail (0.149 (0.016)), inventory control (-0.056 (0.013)), programming (0.052 (0.031)), desktop publishing or newsletters (-0.047 (0.021)), spread sheets (0.079 (0.015)), sales (-0.002 (0.016)). What is striking about these results is that relatively straightforward computer tasks, such as the use of electronic mail, yield the highest wage premium (16.0 per cent) and that the advanced use of computer technology, such as computer programming, yields an insignificant wage premium of only 5.3 per cent. Given the fact that tasks such as programming most likely involve computer skills and the use of email, in relative terms, does not, these results suggest that the computer wage premium might not reflect returns to computer skills.⁶

In addition, most contemporary computer usage concerns emailing and word processing and related activities. This is not exactly the type of specialist knowledge that would only be available among high-skilled workers. Many less highly educated and intermediately educated workers use computers at work (e.g., Table 10.1). Bresnahan (1999) and Handel (1999) show that it is therefore not likely that the demand for more highly educated workers is caused by the need for high-skilled workers to operate computers. In particular many secretaries and typists use PCs intensively. This does not seem to indicate that the use of new technology primarily requires sophisticated computer skills.

A major drawback of the data used by Krueger and many others is that only information about computer use is available and no information about the actual computer skills. Computer skills have been measured only indirectly in the literature as some kind of ‘computer ability’ (Bell, 1996) or ‘computer knowledge’ (DiNardo and Pischke, 1996 and Hamilton, 1997). Bell uses data from the UK *National Child Development Study*. DiNardo and Pischke utilize data from the *West German Qualification and Career Survey* conducted by the Federal Institute for Vocational Training. In this data information on both ‘computer use’ and ‘computer knowledge’ is available. Hamilton uses variables from the 1986 *High School and Beyond Survey* indicating whether an individual has ever used software packages or has used a computer language to program. These three studies find support for the thesis that a number of particular computer skills are rewarded in the labour market while others are not.

Based on data from their 1997 *Skills Survey of the British Workforce*, Green and Dickerson (2004) differentiate four levels of sophistication of computer use: advanced, complex, moderate and straightforward. The higher the complexity of computer use, the higher the wage premium. There is similar information about writing and maths. In addition, the data include the respondents’ self-assessed effectiveness of the use of computer technology, writing and maths. The scale of this variable, which we interpret as a worker’s skill on this task, is constructed from the answer to the following question: ‘If your job involves using . . . are you able to do this effectively?’ The answers are always, nearly always, often, sometimes and hardly ever.⁷ The relationship between the specific writing, maths and computer tasks and wages might result from the skills needed to perform these tasks, but is also likely to reflect unobserved heterogeneity associated with these tasks, indicating that some tasks are more common in jobs with higher earnings than others. Here we are not interested in investigating the relationship between the tasks workers perform and their wages, but in the effects of skills on wages. However, we have to take into account that, as a result of experience, the performance of every specific task will increase the related specific skills, even if they would not be rewarded in the labour market. To distinguish empirically between skills that really matter and skills that are obtained as a by-product of the tasks a worker carries out, we regress the effects of skills on wages given the tasks of a worker:⁸

$$\begin{aligned} \ln W_i = & \alpha + \beta_i X_i + \gamma_1 u_i^1 + \gamma_2 u_i^2 + \gamma_3 u_i^3 + \gamma_4 u_i^4 + \varphi_1 s_i^1 \\ & + \varphi_2 s_i^2 + \varphi_3 s_i^3 + \varphi_4 s_i^4 + \varepsilon_i \end{aligned} \quad (10.2)$$

Table 10.4 OLS regressions for the effect of writing, math and computer skills on pay (dependent variable: log hourly wage (standard errors in brackets))

	Writing	Maths	Computer
Use:			
Straightforward	.105 (.054)	.059 (.055)	.211 (.044)*
Moderate	.100 (.053)	.219 (.055)*	.472 (.077)*
Complex	.169 (.051)*	.186 (.051)*	.554 (.130)*
Advanced	–	–	–.204 (.470)
Skill:			
Straightforward	–.020 (.011)	–.014 (.013)	–.013 (.014)
Moderate	.039 (.013)*	.002 (.013)	–.039 (.023)
Complex	.031 (.011)*	.025 (.012)*	–.043 (.036)
Advanced	–	–	.183 (.123)
Adjusted R ²	.321	.299	.343

Note: * is significant at the 5 per cent level. All data are from the 1997 *Skills Survey of the Employed British Workforce*. For writing the following categories apply: straightforward is filling in forms, moderate is writing short documents with correct spelling and grammar, and complex is writing long documents with correct spelling and grammar. For maths, straightforward is adding and subtracting numbers, moderate is performing calculations, and complex is advanced mathematics. For computer use, straightforward means tasks such as printing etc., moderate is e.g. using a word processor or email program, complex is e.g. using a computer to perform statistical analyses, and advanced is e.g. computer programming and developing software. For writing and maths only three levels of sophistication of use exist in the data.

where s_i^x , $x = 1, \dots, 4$ equal the skills levels for workers who apply writing, maths and computers at the different levels of sophistication and u_i^x , $x = 1, \dots, 4$ equal the use variables. Now, the parameters $\varphi_1, \dots, \varphi_4$ represent the effects of increased skills, conditional on the level of sophistication at which writing, maths or computers are being used. The results of this exercise are given in Table 10.4, which only reports the coefficients on the use and skills variables.

The regression results show that the skills to write both long and short documents have a significant and positive effect on wages. A 1-point increase on the skill scale adds 3–4 per cent to the worker's wage.⁹ The difference between these skills is not statistically significant, however. These regression results for writing skills suggest that there are no large differences between the skills involved in writing long or short documents. The effect of the ability to fill in forms is not significantly different from 0. The regression results reported in the second column of Table 10.4 show that there are

no labour-market returns for the most straightforward maths skills such as adding and subtracting when keeping the level of sophistication of use constant. In addition, there are no returns to skills for calculations using decimals, percentages or fractions. This implies that although the use of this form of maths seems to be typical for higher paid workers, the skill in itself does not appear to be scarce and is not rewarded in terms of wages. Only the ability to apply advanced mathematical procedures has a significant labour-market return of some 2.5 per cent for a 1-point increase on the skills scale, which is somewhat lower than the returns to writing skills. Hence, for most mathematical applications there seems to be a coincidental correlation (unobserved heterogeneity) between the group of workers who use such mathematical applications (and for whom this is important) and their wages. Only for advanced mathematical procedures there seems to be a significant effect of skills on wages. Finally, the estimates reported in the final column of Table 10.4 suggest that computer skills are not important in explaining the wage differentials between computer users and non-users and that these wage differentials are in all likelihood caused by other factors.¹⁰ Only the point estimate for computer skills at the highest level of sophistication of computer use is positive, and the level of significance comes close to 10 per cent, indicating that increases in computer skills might have a substantial effect on the wages of computer programmers and related occupations using computers at the advanced level.¹¹

A number of researchers interpret Krueger's computer wage premium as an indicator of the fact that the introduction of computer technology in the workplace increases wages, that is, computer technology is regarded as a 'treatment'. An employee who is given a computer to use sees his or her wages go up, while an identical employee from an imaginary control group who is not given such a computer will not receive this wage rise. The reasoning is that computer technology increases productivity and that the employee will subsequently have this productivity increase reflected in his or her wages. If we assume that there is competition in the labour market, it is not clear why workers with similar capabilities would not be rewarded similarly. In other words, there is no reason for an employer to pass on the benefits of increased productivity to the employee.¹² Chennells and Van Reenen (1997), Entorf and Kramarz. (1997) and Entorf et al. (1999) studied a panel of employees who started to use computers during the research period. They found that employees who started to use computers did not receive significantly higher wages than the group who did not start to use computers. Entorf et al. concluded that employees with the largest – unobservable – computer talent are selected by the company to use computers. Haisken-DeNew and Schmidt (1999) found similar results for computer usage in a German panel. Bell (1996), on the other hand, did find a

considerable wage increase for computer usage. His study, however, covered a much longer period than the aforementioned analyses. A study by Entorf and Kramarz (1997) shows that employees who use computers annually experience a wage increase that is about 1 per cent greater than average. They interpret this as the market value of the computer experience that individuals have acquired. It is debatable, however, whether this interpretation is correct. After all, the findings could also indicate that it is not the computer usage of each individual worker, but the increased market value of the group as a whole that influences wages. Nevertheless, figures ranging from 15 to 20 per cent higher wages seem odd when moving from a cross-sectional to a longitudinal or panel approach to analyse the data over time.

10.3.2 Firm Level Approach

The idea that the computer wage premium should be regarded as an appreciation of an individual's computer skills implies that only those who actually use a computer will obtain higher wages. A study by Doms et al. (1997) shows that the computer wage premium is unlikely to be an individual, but rather a company-related effect. They find that companies that work with advanced technology, such as computer technology, pay their employees more. It is irrelevant whether employees use the technology or not, they will nevertheless receive a wage premium. Furthermore, it is remarkable that in particular managers who do not themselves use the most advanced technology, receive the highest wage premium from the firm's adoption of advanced technologies. The interesting results from this study are appealing but it is not clear why wages in technologically more advanced firms are generally higher.

In an effort to try a deeper analysis of the results obtained by Doms et al. (1997), a number of studies have focused on understanding the productivity effects from computer technology adoption. Handel and Gittleman (1999) use cross-sectional data from the United States to analyse the effects of high performance measures on the average wages paid by firms. They do not find a significant correlation and interpret this result accordingly. A problem with this conclusion might be that only the average wages within a firm are observed and no information about the quality (education, experience, etc.) of the workers is available. Eriksson (2001) uses Danish data and finds a positive correlation between new organizational designs and high performance measures and the level of education of the firm's workforce. Bauer and Bender (2004) analyse German establishment data in the mid-1990s and obtain a positive correlation between new organizational practices and the wages for, more highly educated workers. Bertschek and Kaiser (2004) obtain similar results for the level of productivity in

German firms. Greenan and Mairesse (1999) find similar results for France. Cappelli and Neumark (1999) investigate the effects of the implementation of high performance measures on both employers and employees in the period 1977–1996 for a panel of US firms. Their estimates suggest that firms gain from the adoption of innovative forms of workplace organization because the productivity of their workers is enhanced. However, when taking into account the costs of the workers the beneficial productivity effect disappears because adopting firms hire more highly educated and more expensive workers. The net effect on the firm's efficiency is almost negligible. These findings suggest that the decision of firms to carry out organizational and technological changes is not based on random events. Firms weigh the costs against the benefits and decide on adoption, so the use of advanced technologies, the demand for different types of workers, organizational structures and revenues can be different between firms, but the differences in terms of profits are relatively minor.

A number of other studies have used firm level data to address the relationship between technological change and the demand for labour more explicitly. Keefe (1991) looks at whether the introduction of numerical control machines led to changes in the demand for skills in the United States in the 1970s and 1980s. His findings suggest that the demand for highly educated labour in 57 different occupations did not increase following the adoption of numerical control machines. Related to this study is a set of four case studies on the demand for labour in large banks. Groot and De Grip (1991) for a large Dutch bank, and Levy and Murnane (1996), Hunter et al. (2001) and Autor et al. (2002) for different US banks analyse the effects of automation on the demand for labour and the composition of the bank's labour force. Their findings suggest that the adoption of different types of computer equipment has led to a number of new tasks that are in general performed by more highly educated workers. In addition, automation of routine activities is observed, which induces workers to focus more on non-routine job tasks. Fernandez (2001) considers the retooling of a large chocolate factory in the United States. His estimates show that computerization has led to upgrading in most occupations, but sometimes jobs have become less advanced and require less skilled workers. However, the overall pattern suggests a higher demand for educated workers.

Finally, a number of studies have analysed the interplay between firm productivity, organizational changes and the demand for labour. The most important studies were carried out by Black and Lynch (2001, 2004) and Bresnahan et al. (2002) for the United States, and by Caroli and Van Reenen (2001) for the United Kingdom and France.

Black and Lynch (2001) analysed the impact of the way in which a firm is organized, ICT and human capital investments on productivity in almost

700 firms in the period 1987–1993 (Black and Lynch, 2004, updated this study and found basically the same results). The authors used data from the *Educational Quality of the Workforce National Employers Survey* (EQW-NES) of 1994 in which, next to the standard demographic information, information about total quality management, benchmarking, the diffusion of computer technology within firms and conditions of employment is available. This database has been merged into the *Longitudinal Research Database* to construct a panel of firms. The performance of a simultaneous analysis of organization, workforce and technology is important because a particular way of organizing the production process associated with a higher level of productivity might have been complemented with the hiring of more highly educated workers. In such a case the effects attributed to organizational changes or the adoption of innovative work practices might be the result of the employment of more highly educated workers only. Black and Lynch follow the companies in the period 1987–1993 to catch the effects of changing capital and labour stocks. A major limitation of their study is that the configuration of the organization within each firm is only observed in 1994, so they need to assume that the organization of work remained constant in the 1987–1993 period. There are at least two potential problems with this assumption. First, it is not possible to control for the correlation between observed firm characteristics and the organizational form. A counter argument is that because of the short time period this is not necessarily a big problem. Second, other studies have shown that especially the period 1985–1995 is characterized by a large number of organizational changes that are most likely correlated with the adoption of computer technologies (e.g., Osterman, 2000). Nevertheless, Black and Lynch (2001, 2004) conclude that the effects of organizational changes on the firm's productivity have been relatively small. They also find that the use of computer technology is associated with higher levels of productivity.

Bresnahan et al. (2002) investigate to what extent innovations in areas such as computer technology, complementary changes in the organization of work and the development of new products or services have induced skill upgrading in the United States. To do so, three different data sources were merged: a panel database in which information about ICT and capital is available for the period 1987–1994; *Compustat* data about production in this period; and a cross-sectional survey performed by the authors in 1995/1996 from which information regarding the firm's organization and employees is available. Organizational changes were measured in terms of the use of modern forms of workplace organization, such as the extent to which a firm is working with self-managing teams, whether there is room for employee voice, the extent to which team building is stimulated, and the space workers have to develop themselves further. In the survey a firm's

human capital is evaluated by the manager on the basis of an evaluation of the skills and level of education of the firm's workforce and the mix of different occupations within the firm. In addition, there is information available about the training and screening of employees. This procedure results in a database including around 300 large US firms. The authors estimate production functions, which suggest a strong correlation between ICT investments, the level of human capital and modern workplace organization. This result is consistent with the individual level studies, which suggest a secular trend towards upgrading when computer technology is being adopted (or is being invested in). In addition, the implementation of ICT in the production process yields productivity gains as large as 40 per cent when this implementation is complemented with organizational amendments.¹³ The crucial factor in being able to estimate these kinds of production functions is that the authors have to assume that it is highly coincidental which managers have implemented the optimal strategy and which have not. The possibility that certain firms changed their organization earlier because the cost-benefit assessment was positive compared to firms that changed later is not excluded in this analysis. If firms decide rationally, and with making mistakes, on their strategy the analysis only explains the optimal relationship between labour demand and organizational change instead of a causal relationship between the two.¹⁴ The same assumption is at the bottom of the analyses of Cappelli and Neumark (1999), Black and Lynch (2001, 2004) and Caroli and Van Reenen (2001). Furthermore, the effectiveness of the form of organization is measured in terms of revenues instead of profits. Firms adopting a strategy of employing more highly educated workers or more capital-intensive inputs are likely to perform better in such an analysis, but the profitability is not necessarily higher.

Caroli and Van Reenen (2001) analyse British and French data to see whether there is skill-biased organizational change independent of the effect of computer technology on the demand for labour. They define organizational change as the way in which the production process is being decentralized. Their paper offers a simple framework to understand the pros and cons of decentralization. The advantages are that the costs of communication are reduced, the organization is better able to adjust to external events and is more flexible, the monitoring of workers is easier and the level of productivity will be increased because workers will be more satisfied when working in a more decentralized environment. The disadvantages of decentralization are the risk of replication of activities, the occurrence of mistakes that will be noticed relatively late in the production process, the loss of economies of scale due to specialization and a possible reduction of the individual worker's efficiency. Along the lines

of this framework the assumption is made that more highly educated workers both reduce the costs of decentralization and raise the benefits. The main reasons for this to occur are that more highly educated workers are better at communicating and more efficient in dealing with (a lot of) information. Next to that the costs of training are lower for highly educated workers and they are better able to work autonomously. Finally, these workers like diversified work more than less highly educated workers. If skill-biased organizational change is present this will be manifested as follows: organizational change leads to skill upgrading; lower wages for more highly educated workers in a certain area (region) have a positive effect on the extent of organizational changes; and firms employing relatively more highly educated workers will actualize higher revenues when they adjust their organization of work.

The estimated coefficients suggest that decentralization of work reduced the demand for less highly educated workers in both France and the United Kingdom in the late 1980s and early 1990s. In addition, firms present in regions with lower relative wages for highly educated workers are more likely to reorganize their workplace to upgrade their workforce. A third finding is that decentralization is more effective in firms already employing a larger share of more highly educated workers. Overall the results suggest a complementary relationship between the demand for more highly educated workers and decentralization, independent of the adoption of computer technology. Nevertheless, there is also an independent effect of computer technology adoption on skill upgrading, which is consistent with the other studies in this area. The likely conclusion from this study is that both technological and organizational changes have an impact on labour demand, but that it is not the complementarity between these forces that determines skill upgrading in France and the United Kingdom.

10.4 A NEW PERSPECTIVE

To obtain a greater understanding of the importance of the introduction of computer technology for the labour market, we study how computers are used and in what way the activities of workers and the organization within the company adapt to this. An essential characteristic of computer technology is that it supports workers in their activities. To determine the influence of computer technology on the way in which a job is carried out, assume a worker has to perform two tasks – task *a* and task *b*. Assume further that these tasks are highly interrelated and that computer technology is able to take over task *a*, but not task *b*.¹⁵ Although the nature of

and the required skills for the tasks may differ greatly, the interrelationship of the activities makes it impossible to separate the tasks into two different jobs, which would have enabled the appointment of two individuals, each of whom would be best qualified for one of the tasks.¹⁶ Finally, assume that task *a* is a routine task and that task *b* is a non-routine job activity.

From this simple setup, we explore two questions. First, when will firms decide to buy computer technology for a particular worker? Second, how will jobs change when computer technology is implemented?

10.4.1 When to Adopt Computer Technology

The efficiency of the production process increases when an individual is able to carry out tasks faster as a result of computer technology. The time gained may relate to the work that is computerized or to the work that cannot be taken over by the computer. If task *a* is automated, the time required to carry out the task itself is replaced by the time that is required to operate the computer. The largest gain can therefore be achieved if task *a* can easily be computerized and the user is able to handle the computer effectively. In principle, the activities that cannot be computerized will continue to take as much time as before. It is also possible, however, that the introduction of computer technology makes it possible to carry out task *b* more efficiently. This reflects the possibility that technology and labour are complementary. Accountancy might be a good example of an occupation in which task *b* gains from such a complementary relationship. Accountants today need not do their calculations by means of mental arithmetic or use a notebook to check a company's books. They will use computers and spreadsheet applications to add up numbers, divide figures, and so on. Accountants can now concentrate entirely on analysing and checking (by means of the computer) the accuracy of the figures and detect any errors or fraud more quickly if the figures are incorrect. If the complementarity of the two tasks is high, task *b* (the analysis) will also be completed in less time.

There are three points of view with respect to the employment effects of computer usage representing extreme examples of this conceptual framework. In the view that expects computers to take over the work of human beings, work consists merely of task *a* that can be automated and there is little or no time required to operate the machine. As it is in particular the less highly educated workers who perform such tasks, they are the first to fall victim. The second view states that work consists only of task *a*, but that computer skills are so important that keeping computers running requires a great deal of time and specific skills. As it is expected that more highly educated workers have such skills (or adapt more easily to new technology), they will be the ones who carry out this computer work. Lastly,

there is a view in which complementary skills determine the value of computer usage. Here the task to be automated is marginal and there is not much time to be gained. The advantage should then be obtained from increased efficiency of the complementary tasks (task *b*).

It is interesting to see that even when computer skills are not important and there are no complementarity advantages to be gained, the introduction of computer technology can nevertheless achieve time gains without the work disappearing completely. In this case, the employee need only carry out task *b*, while the computer takes over task *a* completely.

A firm will only decide to introduce computer technology if the costs involved match the time that can be gained.¹⁷ Time gained in the production process is translated into a productivity increase and constitutes savings on labour costs. It is therefore attractive to acquire computer technology if the costs of the setup are lower than the wages that must be recovered. In addition to the amount of time saved, the wages of the worker involved will determine whether computer technology will be beneficial to the firm. This appears to be true even when the wages are not a proper reflection of productivity. If various institutional factors cause the wages in a particular occupational group to be relatively high compared to other occupational groups, *ceteris paribus*, computer technology will be introduced more rapidly. The mechanism that determines when computer technology is introduced at the workplace therefore depends on the wages earned by individuals rather than the computer skills or complementary skills of these workers.

This observation reverses the causality between wages and computer technology adoption suggested by previous studies. Even when we correct for personal characteristics and job characteristics, wage fluctuations explain the probability of individuals adopting computer technology. Hence, the observation that more highly educated workers have adopted computer technology earlier on and that their incidence of computer technology use is higher does not seem to be a reflection of their higher level of education or skills, but is more likely to be the result of their higher wages.

Another result we can derive from our setup is that the less relevant the technology is for the job, the greater the wage difference must be to make its purchase profitable. This is consistent with the results of Krueger, who finds that relatively trivial tasks, such as emailing and word processing, have a great impact on wages. If a manager and an assistant spend an equal amount of time on the same task, and they are both equally good at it, then the benefits of computerization will compensate the costs more easily in the case of the manager.

Productivity differences may emerge, however, because an individual is capable of producing products of greater value or higher quality, but these

may also arise because one person is able to carry out the work faster than another. Just like higher wages indicate greater speed of working, investments in computer technology will be made less easily. After all, in the case of faster workers there is less time to be gained by computers taking over the work.

Following this line of reasoning, we can state that when the costs of computer usage are reduced further, the introduction of the computer will become profitable for other jobs too. If the costs were reduced to zero, all jobs in which the introduction of computer technology could result in time gain, would do so. If the possible applications and efficiency of computer technology increase further, the group of jobs in which useful application is possible will also grow. If the costs are reduced sufficiently and the areas of application increase, eventually almost every worker will probably use computer technology.

For a large part, the costs of the introduction of computer technology do not depend on the number of employees in a company or department who make use of the technology, but follow on from the development and implementation in the company or department as a whole. As people must be able to work together within a department, it will often be difficult to allow some workers to use computer or communication systems and not others. As a result, it is to some extent not the individual wages, but the average wages of the department in which one works that affect the decision whether or not to adopt computer technology.¹⁸

10.4.2 Productivity, Demand and Wages

The introduction of computer technology leads to productivity increases. In terms of our framework, these are equal to the relative time gain achieved in the production process as a result of the computerization of task *a*. If the total production volume remains the same, the demand for employees in this profession will decrease by a similar percentage. Production costs decrease less, because the decreasing wage costs are offset by the increasing costs for the use of computer technology. In addition to this immediate reduction of the demand for labour as a result of productivity increases, the lower cost price per unit of product will lead to an increase in demand for the product concerned and hence indirectly to higher demand for the labour involved. Eventually, the effect on employment depends on the size of the two effects. If demand is characterized by high price elasticity, efficiency improvements may lead to an increase in the demand for labour and this will create an upward pressure on wages.¹⁹ If we assume that computer technology is introduced in particular among the more highly educated workers, there will only be skill-biased technological

change if this elasticity is sufficiently large, that is, an improvement in the position of the more highly educated workers in relation to the position of the less highly educated. In addition, if the costs of computer usage have decreased to such an extent after some time that computer technology is introduced in all jobs in which time can be gained, these demand effects are equally likely to occur among less highly educated workers. Eventually, the effect of computer technology on the demand for labour through this route, seems ambiguous and it is not likely that we will find the main explanation for long-term skill-biased technological change here.²⁰

10.4.3 Skills and Education

We have argued that even if computer skills play no role and there is no complementarity in which certain skills come into their own better because of the use of computers, the adoption of computer technology can nevertheless be explained, and it is plausible that workers with high wages are the first to make use of computer technology. Even without an explicit role for computer skills and complementary skills, the value of different skills in the labour market will start to shift as a result of the adoption and diffusion of computer technology. After all, the structure of the work is shifting, making the skills that promote productivity in the remaining work more important, whereas the importance of the skills that were required for the work that is now done through computer technology will decrease.

The education and qualification requirements set by an employer for a particular job, can be regarded as a balance between the higher wages that must be paid for a more highly educated employee and the additional productivity that such an employee may provide. In a job in which a more highly educated employee adds little to productivity compared with a less highly educated employee, educational requirements will therefore not easily be raised. It seems reasonable to assume that a more highly educated worker will yield productivity benefits in particular in those activities that cannot easily be automated.

Before computer technology was introduced, increasing educational requirements meant that highly paid workers would also do work in task *a* in which they were no better than workers with a lower educational background. This acted as a restraint on the qualification requirements that were set. After the introduction of computer technology, activities such as task *a* no longer play a role. Even if the highly educated worker is not more adept at carrying out the computerized task *a*, it may be expected that employers will increase their educational requirements, because the importance of task *b* increases. Groot and De Grip (1991) were among the first to

show that the introduction of computer technology leads to higher educational requirements. By comparing various branches of a large Dutch bank, which introduced *front office* and *back office* automation at different moments in time, they were able to show that automated branches did indeed increase their educational requirements.²¹

This shift in the importance of tasks also constitutes a possible cause of skill-biased technological change. Whether it is a high-skilled job or a low-skilled job, after the introduction of computer technology we may expect a gradual increase in the educational requirements of the job concerned. Within each job, it is not a change from requiring an unskilled worker to an academic, but as an aggregate these demand shifts will change the employment structure as a whole. It can be expected that this effect is much more likely to lead to skill-biased technological change than the previous possible effects. After all, shifts in demand can be both to the advantage and to the disadvantage of the more highly educated, while this increase in educational requirements within a particular job almost always moves in the same upward direction.

10.4.4 Is Work Becoming More Complex or More Standardized?

Just as an employer may consider which educational level to demand for a particular job, he or she may also vary the nature of the product by putting greater emphasis on task *a* that can be computerized, or instead on task *b* that cannot be computerized. The choice of the product to manufacture will depend on the costs and benefits of the various combinations. If a product is standardized, it is likely that a greater part of the work will be routine and capable of being automated. The costs will drop, but the value of the product will also decrease. On the other hand, more tailor-made work will be required for a greater amount of work that is difficult to automate. This will lead to higher costs, but will probably also make the product more valuable. The product actually manufactured is therefore determined by the balance between these factors. The introduction of computer applications will also upset this balance.

On the one hand, as we have indicated above, the routine part of the work becomes cheaper as a result of the introduction of computer technology. This will give rise to a tendency to standardize the product. On the other hand, complementarity will also increase the productivity of non-routine work. If this latter effect dominates, there would be a renewed trend to supply more tailor-made products. The eventual changes in the product will therefore depend on the cost savings in the routine part on the one hand, and the achieved complementarity advantages on the other.

10.5 CONCLUDING REMARKS

The adoption and rapid diffusion of computer technology have drastically changed the labour market. Many tasks have been computerized and many workers are able to work more efficiently. As a result, the labour market is also affected to a great extent by computer technology in PCs, but also in other ICT applications. Further diffusion of new computer technology is likely only to increase the importance of computers and computer-related technology.

In this chapter we have discussed the way in which people work together with computer technology. On the basis of this analysis of the interaction between worker and machine, we have shown which workers use computer applications, what influence this has had on the content of their work, and what the implications are for the demand for various types of labour. Considered from the current view on the effects of computer technology on employment, our findings shed new light on the relationship between computer technology and the labour market. It is true that new computer techniques are initially used more by more highly educated than by less highly educated workers, but this is often used to arrive at the conclusion that special computer skills are needed to be able to use this new technology. Our results suggest that the primary aspect is not the high educational level but the high wage that explains the earlier adoption of computer technology in these groups. For workers with high wages, a small increase in productivity results in greater cost savings. As computer technology becomes cheaper and more interesting applications emerge – we expect – almost everybody will come into contact with computer technology at the workplace. Because these new applications are meant to support people in their work, the use of this new technology will create few problems with regard to skills.

This does not mean that nothing has changed. The use of computer technology has increased productivity in many occupations. On the one hand, this has decreased the demand for the category of labour concerned, but on the other hand the lower production costs also decrease the production price, which in turn increases demand. As a result of such processes, the importance of certain activities will increase while that of others will decrease. As we expect that eventually both the more and the less highly educated will use computer applications in their work, and these production increases may have both a positive and a negative effect on demand, a long-term effect on relative wages is not expected.

As ICT applications take over work from human beings, the importance of various types of skills will undergo major changes in the near future. On the basis of the new production options, employers will reconsider the product range that their companies supply and the working methods used.

In certain circumstances, we expect that there will be more tailor-made products, while under other conditions there will be greater standardization of products. Some will benefit from the shift in the importance of skills on the labour market, while others will suffer disadvantages. Again, we do not expect that this process will be clearly to the advantage of the more highly educated, because it is not only the value of skills relating to cognitive intelligence that will increase.

The third effect of greater penetration of computer technology is that individuals at work are able to concentrate more on those activities that constitute the essence of their profession. Many secondary tasks will be taken over by the new technology. This means that employers will tend to increase the required qualifications within the various professions. After all, the costs of higher wages will be compensated by the fact that less time is lost on tasks in which these skills are not used. It is in particular this argument that gives rise to the expectation that the demand for more highly educated workers will continue to grow. This form of skill upgrading, however, is unlikely to lead to a situation in which there is no work for the less highly educated and an increasing scarcity of more highly educated workers, resulting in a threatening digital split of society. The gradual nature of these shifts means that in the time to come, almost everybody will study longer and will need to spend a little more energy on increasing and maintaining knowledge levels in order to be able to continue functioning properly on the labour market.

Finally, it cannot yet be predicted how exactly the labour market will further change as a result of the adoption and diffusion of computer technology. This depends to a large extent on the applications that are still to be developed, while the response to these developments may be very complex. It seems therefore of great importance to carefully monitor developments in the labour market, because only then will it become clear in time in which direction the labour market is moving. This demands different perspectives in research and hence also a new type of (experimental) data collection, with much greater emphasis on the nature and content of the work, the required competences, and the available knowledge and skills of workers. Such an instrument would serve both research and policy-making. To be able to follow labour-market developments adequately in the future, we will need to develop the tools used to measure skills, and researchers will need to have the possibility to test their insights in the developments on the labour markets against real-life situations. For policy-makers, such instruments may constitute the basis for policies in the field of education and training enabling them also to keep a finger on the pulse in a knowledge-based economy.

NOTES

1. Katz and Autor (1999), Katz (2000), Acemoglu (2002), Aghion (2002), Card and DiNardo (2002) and Autor et al. (2004) provide useful overviews of the body of literature on the computerization of the labour market.
2. Microsoft interpreted the observed wage differential as a premium for using a PC. In the early 1990s they used the computer wage premium in an advertising campaign to suggest that using Microsoft software yields wage gains up to 20 per cent.
3. A different problem with this information is that the use of computer technology is measured by the direct use of (personal) computers by workers. While this measure is incomplete and misses workers who use devices with embedded microprocessors, it does reflect a particularly prevalent form of computer technology that has been important in both the production process and in facilitating modern forms of communication within most firms.
4. The relationship between age and computer use at work is addressed at length in Borghans and Ter Weel (2002) for Britain, Weinberg (2002) and Friedberg (2003) for the United States and Aubert et al. (2004) for France.
5. Weinberg (2000) has explained this observation by arguing that jobs which previously required a great deal of physical strength and stamina have been transformed into more women-friendly jobs after the introduction of computer technology. Also computers seem to be more heavily used in occupations in which women are particularly present.
6. Entorf and Kramarz (1997) and Entorf et al. (1999) report similar findings but attribute such results to unobserved heterogeneity. Doms et al. (1997) examine the use of advanced technologies by firms. They distinguish between plants using less than 4 technologies, plants using 4 to 6, 7 to 8, 9 to 10, 11 to 13 and plants using more than 13 technologies. Their results suggest a monotonically increasing relationship between technology use and the educational level of the workforce. Finally, Haisken-DeNew and Schmidt (1999) show that in Germany no computer wage premium can be obtained when they control for unobserved heterogeneity. See also a recent study by Lang (2001) for an interpretation of the premium.
7. Borghans and Ter Weel (2005) offer an elaborate discussion of the robustness of this skill measure. See also Spenner (1985) for an assessment of the robustness of self-assessed skills.
8. See Borghans and Ter Weel (2004a) for a more formal treatment and derivation of the underlying theoretical structure.
9. The finding of DiNardo and Pischke (1997) that a worker who uses a pen earns more than the average worker, can therefore be understood as a return to writing skills. Of course, not every worker who uses a pen will earn more, but within the group of pen users there is a large fraction of people who have to write short or long documents and whose skills to do so are rewarded in the labour market. Trivial skills involving a pen have no returns.
10. If computer skills are important in the labour market and the spread of computer technology has made them a scarce commodity, it can be expected that employers will try to ensure that anyone who has such skills does work in which they are important. DiNardo and Pischke (1996), however, show that in Germany it is not the case that all those who possess computer skills are working in jobs in which computer technology is used. On the other hand, quite a large number of people have jobs in which computers are used, even though they have no computer skills. Also, people who use computers at work frequently switch to jobs in which computers are not used.
11. The fact that the coefficient is not significant at the 5 per cent level might also be due to the rather small number of people in the sample using computers at the advanced level.
12. To deal with this problem, Gould et al. (2001) and Aghion et al. (2002) argue that workers differ in their adaptability to new technology as a result of random shocks or

- luck, and Violante (2002) argues that workers are matched to jobs based on unobserved quality differentials.
13. Darby and Zucker (1999) and Gale et al. (2002) found similar results for Japanese and US biotech companies and a cross-section of about 3,000 US firms, respectively.
 14. Bresnahan et al. (2002) were concerned about this criticism and try to make their assumption credible in their section 5.
 15. Autor et al. (2003) and Spitz (2003) offer related theoretical considerations of modelling the way in which computer technology has changed the work from routine to non-routine tasks.
 16. Borghans and Ter Weel (2004b) consider a case where it is possible to split the tasks into different jobs. They derive that it is profitable to do so if the wage differential between workers carrying out the tasks is relatively large, the coordination costs are low, if skilled (unskilled) workers have a comparative advantage in skilled (unskilled) tasks and if the task that is handled by computer technology is a relatively time-consuming one.
 17. Autor et al. (1998) and Borghans and Ter Weel (2003) calculate that the average annual rent of computer technology for a US worker in the late 1990s was about \$6,500. This figure exceeds 20 per cent of the average US worker's annual wage. These are the cost for the entire deal (i.e., hardware, software, maintenance, furniture, etc.).
 18. Borghans and Ter Weel (2004b) formally show that the decision to adopt computer technology for the department or firm as a whole is determined by the average wages in the department or firm. The mechanism explored for individual workers remains the same though.
 19. This is only a partial effect on wages. Because computer technology will change the demand for a variety of professions, and wage changes in one submarket may affect other submarkets, it is difficult to get an overview of the final effects in a general balance.
 20. Borghans and Ter Weel (2003) develop a more formal technology diffusion model in which these effects are shown to be consistent with the wage structures of the United States and Germany since the 1970s.
 21. Doms et al. (1997) and Autor et al. (1998) find similar 'upgrading' effects for the United States. Levy and Murnane (1996), Fernandez (2001) and Autor et al. (2002) carry out case studies for US firms and derive similar results.

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