HAS TECHNOLOGY HURT LESS SKILLED WORKERS?

AN ECONOMETRIC SURVEY OF THE EFFECTS OF TECHNICAL CHANGE ON THE STRUCTURE OF PAY AND JOBS

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Abstract

There is a growing concern in advanced countries that the position of less skilled workers has deteriorated, either through their ability to secure jobs and/or their ability to earn a decent wage. Some have linked this decline to modern computing technologies. This paper surveys the evidence on the effects of technical change on skills, wages and employment by examining the micro-econometric evidence (we take this to include studies at the industry, firm, plant and individual levels). We focus on over 70 empirical studies that have used direct measures of technology (rather than associating technology with a residual time trend). We first point to three basic methodological problems relating to endogeneity, fixed effects and measurement. Our survey comes to the following tentative conclusions:

(i) there is a strong effect of technology on skills in the cross section which appears reasonably robust to various econometric problems;

(ii) there is a strong effect of diffusion of technologies on wages in the cross section which is not robust to endogeneity and fixed effects;

(iii) at the firm level product innovations appear to raise employment growth, but there is no clear evidence of a robust effect (either positive or negative) of process innovations or R&D on jobs.

Keywords: Employment; Wages; Skills; Technology;

JEL Classification: J51, O33.

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1. INTRODUCTION

The effect of the development of tools on the evolution of human activity has long been a principal concern for students of social behaviour. Marx viewed the development of the productive means as the key force in the evolution of human history. The identity of the dominant class was determined by their ability to best muster the development of technology. In neo-classical economics, technological progress is also regarded as the driving force behind economic growth, a notion that is reinforced by endogenous growth theory. Given its role in economic growth, technical progress leads to higher standards of living on average. But how are the benefits of technical progress distributed across society?

In the past, many commentators have worried that technology could lead to a 'de-skilling' of workers. The pin factory symbolises the destruction of skilled artisans and their replacement by workers who were required only to perform the most menial repetitive tasks (Braverman, 1973; Edwards, 1979). More recently, however, debates by economists have focused on whether modern technologies are generally biased towards more skilled workers. The participants are particularly vocal in the debate over the causes of the increasing inequality of wages and employment between the skilled and the unskilled. Although closely related to it, the existence of skill-biased technical change does not provide the explanation for recent changes in the wage and employment structure. To demonstrate that technology is biased towards more skilled labour is not sufficient (and some would argue not even necessary - see Leamer, 1994) to establish technical change as the dominant explanation for increases in inequality. We also have to consider the supply of skills, for example.

The purpose of this paper is quite modest. We seek to survey econometric work which analyses the association of observable measures of technology with skills, wages and employment. Our focus is mainly at the enterprise level, but we also consider some studies at the industry and individual level. The survey attempts to be comprehensive, but is limited to English language papers and is heavily biased towards publications in economic journals. Macro-econometric studies and case studies[1] are outside the scope of this paper. We seek to identify empirical regularities and also to evaluate the main methodologies critically. This is intended to help point the direction for future work in this rapidly growing area.

The plan of the paper is as follows. Section 2 briefly discusses some theory which implicitly or explicitly forms the background of the empirical studies. Section 3 discusses empirical problems with implementing the theory. Section 4 discusses the results of the papers explicitly and Section 5 draws some conclusions.

2. THEORETICAL GUIDE[2]

2.1 The skill bias of technical change

We start with a general framework based within the context of a neo-classical model of production. For simplicity we consider the case of three variable factors (skilled labour, unskilled labour and materials) and two quasi-fixed factors (physical capital, denoted by *K*, and "technological capital", denoted by *R*). Consider a quasi-fixed translog cost function:

$$\ln C = \alpha_0 + \sum_h \sum_{i=B,W,M} \alpha_{hi} D_h \ln w_i + \sum_{i=B,W,M} \sum_{j=B,W,M} \beta_{ij} \ln w_i \ln w_j + \beta_q \ln q +$$
$$\sum_{j=B,W,M} \beta_{iq} \ln w_i \ln q + \beta_K \ln K + \sum_{j=B,W,M} \beta_{iK} \ln w_i \ln K + \beta_R \ln R + \sum_{j=B,W,M} \beta_{iR} \ln w_i \ln R$$

(1)

where C are the variable costs (blue-collar labour - *B*, white collar labour - *W* and materials - *M*). The α parameters reflect own price effects. We allow these to differ in different 'units', indexed by D_h. (*D* = 1 if in unit *h*, etc). For example, we might allow the own price effects to vary in different industries or even different firms (fixed effects). The β parameters measure the effect on total cost of the other factor prices (*w*), the log of plant output (*q*), technology (*R*) and the capital stock (*K*).

Since cost is homogeneous of degree one in prices, there are a series of restrictions as follows:

$$\sum_{j=B,W,M}\beta_{ij} = \sum_{i=B,W,M}\beta_{ij} = \sum_{i=B,W,M}\sum_{j=B,W,M}\beta_{ij} = \sum_{i=B,W,M}\beta_{iR} = \sum_{i=B,W,M}\beta_{iK}$$

(2)

These allow equation (1) to be normalised by one of the factor prices. Taking the materials price (w_M) as the unit of normalisation, we obtain a normalised translog cost function where costs (relative to materials price) are a function of the relative prices, output, capital, technology and their interactions. From Shephard's lemma, the cost share s_I for input I is given as:

Unskilled Workers

$$S_B = \alpha_B + \sum_{i=B,W}\beta_B \ln(w_i / w_m) + \beta_{Bq}\ln q + \beta_{BK}\ln K + \beta_{BR}\ln R$$

(3a)

Skilled Workers

$$S_W = \alpha_W + \sum_{i=B,W} \beta_W \ln(w_i / w_m) + \beta_{Wq} \ln q + \beta_{WK} \ln K + \beta_{WR} \ln R$$

(3b)

Note that the materials equation has been dropped because the cost shares sum to unity.

We can test for homotheticity of the structure of production (i.e. that the cost shares are independent of the levels of output and the quasi-fixed factors) by imposing the following restrictions:

$\beta_{iq} = -(\beta_{iR} + \beta_{iK})$, where $i = B, W$

If these can be accepted, the cost share equations simplify to:

Unskilled Workers

$$S_B = \alpha_B + \sum_{i=B,W} \beta_B \ln(w_i / w_m) + \beta_{BK} \ln(K / q) + \beta_{BR} \ln(R / q)$$

(4a)

Skilled Workers

$$S_W = \alpha_W + \sum_{i=B,W} \beta_W \ln(w_i / w_m) + \beta_{WK} \ln(K / q) + \beta_{WR} \ln(R / q)$$

(4b)

The elasticities of substitution and complementarity can now be calculated. In terms of the technology variable, if the coefficients $\beta_{WR} > 0$ and $\beta_{BR} > 0$, we would say that technology is labour-biased. If $\beta_{WR} > 0$ and $\beta_{BR} < 0$, then technology is skill biased[1].

The formulation is often further simplified using value added (*VA*) rather than output. In this case the dependent variable is the share of skilled labour in the wage bill, and the factor demand equation is simply:

Skilled Workers

$$S_W = \alpha_W + \beta_W \ln(w_W / w_B) + \beta_{WK} \ln(K / VA) + \beta_{WR} \ln(R / VA)$$

(5)

Again, skill biased technical change would be indicated by a positive coefficient on β_{WR}.

Versions of this structure are very common in the literature. It seems a natural one given the difficulties in accurately measuring a cost of physical or technological capital (especially one that varies exogenously across microeconomic units). Sometimes the physical capital factor is allowed to be variable and only the technological component is fixed (e.g. Duguet and Greenan, 1997).

Many researchers have estimated equation (5) in employment shares rather than cost shares. Although less appropriate from a theoretical point of view, this clearly has the advantage that it allows a statistical decomposition of the effects of technology into a relative wage component and a relative employment component.

This is only a framework for organising our thoughts over the effects of technology in a well-known neo-classical framework. Other models suggest different rationalisations for the correlation of technology with cost shares. For example, the neo-classical model here takes factor prices as exogenous, which is clearly a questionable assumption since wage-setting is not conducted in a competitive spot market. Models of bargaining would suggest that workers

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[1] In fact things are more complicated than this as strictly speaking the Allen elasticity of substitution will also depend on the cross correlation between the quasi-fixed factors (see Brown and Christensen, 1981, for a full treatment)

may be able to ‘capture’ some of the rents from innovation. If skilled workers are more able to do this than unskilled workers (because of higher turnover costs associated with more skilled employees, for example), then the technology-cost share correlation could be driven by relative wage movements rather than relative employment movements. This underlines the importance of analysing movements in factor prices and quantities.

The literature on the effects of technology on wages has been primarily motivated by attempts to assess the productivity effects of computers on highly skilled workers. Note that a competitive labour market would only have one wage for each skill type, so the underlying model behind these correlations is not entirely clear.

The rent-sharing story is not the only potential reason for finding higher wages in firms with relatively intensive R&D expenditures. Another explanation could be related to employment contracts. If part of a worker’s wage is tied to the performance of the firm (to reduce shirking for example), then workers will demand a higher mean compensation in a more risky environment (assuming that R&D intensive firms face, ceteris paribus, a higher variance in their performance over time than non-R&D intensive firms). Garen (1993) has found evidence for this in his examination of managerial remuneration.

The impact on labour demand can be derived from the structure outlined above. One problem with this, of course, is that much of the effect of innovation might derive from increased output, which implies estimating the production function directly. In fact, most researchers have tended to estimate simpler equations of employment based on aggregating across all workers and estimating employment growth equations.

There are, of course, serious difficulties in extrapolating results from the micro-level to produce macro-level implications. We have focused on the demand side, but the equilibrium effects of technological change will also depend on what is happening in other areas of the economy, and in particular to the supply of more skilled labour. Furthermore, reallocations of output and employment will occur within and between sectors that will tend to complicate the aggregate effects. The micro-econometric evidence is only a small part of the story, and researchers should resist extrapolating too much from these partial equilibrium results.

2.2 Skill bias and unemployment

In this section we consider what the implications of our model of skill biased technical change are for unemployment and jobs. There are a great number of complex interactions between innovation and employment but we begin with what we think is the most important route.

If technology is skill biased an exogenous increase in the stock of technological capital (a ‘technology shock’) will increase the demand for skilled labour relative to unskilled labour. As the demand curve shifts out, in equilibrium there is both a rise in the relative wages and the relative employment of the more skilled group.

Note that there is no unemployment in this model since the labour market clears. Now consider introducing some institutional limits to how far the wages of less skilled workers can fall. These could arise due to minimum welfare levels, minimum wages, trade unions or efficiency wage considerations. In this case there will be less of an increase in wage inequality, but there will be some unemployment for unskilled workers.

This is not a new idea. More recently, this story has become the dominant view of changes in the labour markets of the industrialised countries in the last 20 years. In the flexible labour market of the US, wage inequality has increased and unemployment has remained stable. In the relatively inflexible labour markets of Europe (outside the UK), wage inequality has been stable but unemployment has increased dramatically. Paul Krugman (1996) has christened US inequality and European unemployment as "two sides of the same coin".

The debate on these matters is fierce. As noted in the introduction, the existence of skill biased technical change and the question of whether technology is responsible for recent labour market trends are related, but quite distinct analytical issues. Explaining recent history is a far harder task than simply understanding skill bias. This is not least because of strong disagreement on the appropriate model of the labour market.

There are three key questions to be addressed.

1. Has the demand for skilled workers outstripped the supply of skilled workers? Or more accurately, has the demand/supply gap become greater over time?
2. If demand has accelerated relative to supply, is this due to technical change or some other factor, such as increased trade with less developed countries?
3. If the answer to both 1. and 2. is yes, how much of the change in unemployment and inequality can be accounted for?

Has the demand for skilled workers outstripped the supply of skilled workers?

Katz and Murphy (1992) and Autor, Katz and Krueger (1997) try to date the timing of the increase in demand for skills in the U.S. They use a weighted average of the growth of relative wages and employment, assuming that the labour market is in equilibrium with no unemployment. Given an assumption over the degree of substitutability between the skilled and the unskilled, it is possible to use a CES production function to estimate the relative employment changes. It is very hard, however, to date precisely the timing of the acceleration in demand, although both authors argue it exists (cf. Mishel and Schmitt, 1996).

More general methodologies have been proposed to take into account the unemployment in Europe and elsewhere. Nickell and Bell (1995), Jackman et al (1996), Manacorda and Manning (1997) argue that there has been relatively little increase in mismatch outside the UK and US and that most of the increase in European unemployment has other roots.

Has the demand change been due to technical change?

There is greater agreement that, to the extent that demand has shifted towards the skilled, this is due to technology rather than trade. The methodologies used to reach this conclusion are based the fact that most of the change in skills has been a within industry phenomenon (see Berman et al, 1998, for more discussion of this debate).

How much can technology account for?

This question needs a full general equilibrium analysis which has rarely been attempted (see Minford et al, 1997, for one attempt). Back of the envelope calculations in Machin and Van Reenen (1998) suggest that technological factors alone can only account for a third or less of the changes in the US and UK, but far more outside these two countries.

2.3 Technology, homogenous labour and employment

The debate of the previous section is a crucial one for policy makers. Yet there is another strand in the literature which asks whether technology is responsible for falls in jobs *even when it is not skill biased*. Although a great deal has been written on this topic, the literature and the surrounding policy debate are littered with confusions.

Information and Communication Technologies (ICTs) have diffused rapidly in Europe over the last 20 years and unemployment has also risen. The temptation is strong to suggest that there is a causal link between the two. Yet waves of technology have passed over Europe in the past without creating persistent and structural unemployment. The debate over technological unemployment on the other hand has proved persistent. Similar arguments were being made in the 1960s over the introduction of automation, while in the 1930s Lord Kaldor

(1932) commented (in a paper relating to the unemployment in the Great Depression):

"Today there is scarcely any political or journalistic observer of world affairs who does not attribute to the rapid growth of technical improvements one of the major causes of the present trouble".

Yet the fact remains that an examination of long-run unemployment trends shows no upward trend, despite the presence of technical change for several hundred years. It is possible that technology has a temporary destabilising effect on employment, but it is difficult to believe that it is the major cause of the recent rise in European unemployment levels. Only technology combined with something else - such as wage rigidity - could be part of the cause.

What can economic theory tell us about the likely effects of technical change on employment? One form of technological change to consider is labour-augmenting process innovations. This case has been explored thoroughly in the literature. There are essentially two forces at work. For a given level of output, this type of technical change means that employment must fall since the same output can be produced with a lower level of inputs. To offset this, however, is the fact that output will increase as prices fall, because costs have fallen. This is the primary 'compensation mechanism' of technical change. It means that examining the impact of technology on output (the production function relationship) is fundamental to understanding the effects of technology on output.

In Appendix I we consider a simple model which shows how the effects of technical change work. This model leads us to the following results:

1. *Price elasticity of product demand.* The greater is the sensitivity of consumers to price changes the more likely it is that an innovation will raise employment. The higher is the price elasticity the greater the increase in output generated by an innovation.
2. *Substitution of capital for labour.* The easier it is to substitute the more likely it is there will be positive employment effects of labour augmenting technical change, since labour is now relatively cheaper than capital and the firm will substitute into labour. The opposite is true for capital augmenting technical change.
3. *Monopoly power.* If the firm has some degree of market power not all of the reduction in cost will be passed on in the form of lower prices. This will blunt the output expansion effect and make positive employment effects less likely.

Generalisations of the model lead to the consideration of further possible effects.

4. *Market share effects.* If the innovation does not diffuse immediately throughout the industry, the firm will have a cost advantage and so will tend to expand at the expense of its rivals. This will mean larger effects at the firm level in the short run. It also means that researchers should be careful in generalising from the micro-results to the economy level.

5. *Union effects.* If some of the efficiency gains from innovation are captured by unions in the form of higher wages (or reduced effort, etc), this will also blunt the output expansion effects. The results are uncertain if the union also bargains over the wage (see Ulph and Ulph, 1994).

6. *Product Innovation.* Product innovations will tend to have stronger output expansion effects and are therefore more likely to result in employment increases (see Katsoulacos, 1984, for a fuller analysis)

7. *Economies of scale.* These will tend to magnify the positive employment effects.

3. ECONOMETRIC MODELS

We discuss some econometric problems focusing on fixed effects, endogeneity and measurement. Consider the basic equation to be estimated as the stochastic form of equation (5)

$$S_W = \alpha_W + \beta_W \ln(w_W / w_B) + \beta_{WK} \ln(K / VA) + \beta_{WR} \ln(R / VA) + u$$

(6)

where u represents a stochastic error term. This could be justified by allowing the α_W to be random across units, or due to measurement error or optimisation mistakes. It is unlikely, however, that the error term is uncorrelated with other right hand side variables. Some firms may have dynamic managers who employ both top quality workers and high quality technology. For this reason, controlling for fixed effects is important and researchers might estimate the equation in differences (or by including dummies if the time series is long enough):

$$\Delta S_W = \beta_W \Delta \ln(w_W / w_B) + \beta_{WK} \Delta \ln(K / VA) + \beta_{WR} \Delta \ln(R / VA) + t + e$$

(7)

where t denotes time dummies, and e the error term. Unfortunately, estimating this type of model usually requires panel data, which is rare in the firm level work. This is one reason why most research has focused until recently on the industry level.

A second fundamental problem is dealing with the issue of endogeneity. Even when unobserved heteroegeneity is removed, firms might still change their technology in response to a change in the make-up of skills available, rather than vice versa. If the 'technological' factor was completely fixed in the short-run, this would not be an issue. This may be more plausible for R&D than for other technology proxies (such as computer use). The use of longer differences (used to mitigate such problems as measurement error) will actually exacerbate these problems of endogeneity. The only solution is to develop instrumental variables to deal with the fact that the technology and the skills decisions are being taken simultaneously. Unfortunately, such instruments are not easy to find, and researchers have been rightly reluctant to use the standard econometric approach of using lags because of concerns that they are weak instruments.

A related issue is the even greater concern over the interpretation of the coefficients on the relative wage terms. These terms are directly involved in the construction of the dependent variable. It is doubtful how much of the inter-firm or inter-industry variation in relative wages is due to changes in the price of labour, rather than due to changes in the quality mix of labour which is imperfectly captured by observable skill. An intellectually respectable solution would be to use credible instruments for prices. One commonly encountered short cut in the literature is to argue that time dummies will capture the real variation in wages, and to include these instead of the relative wage terms.

The third and perhaps the most basic issue, however, is the problem of measurement of technology. This is a very serious problem, since the technology input is a far more nebulous concept than the input of, say, labour, which in itself is difficult enough to measure. The traditional approach is simply to use time trends. The problem here, of course, is that the trends are likely to be picking up a lot more than just technical change, such as unmeasured price movements, changing demand conditions, cost shocks and so on. These criticisms are well known from the debate on how suitable total factor productivity (TFP) is as a measure of technology.

Researchers have turned to a variety of alternatives in seeking observable measures of technology. We can distinguish crudely between three types of measure, which correspond to inputs into the knowledge production function, outputs from the knowledge production function and subsequent diffusion of these outputs around the economy.[3] Inputs are generally measured by R&D activities. R&D expenditure has the advantage that it is measured in many databases over time, across countries and in a reasonably standard way[4] - at least by comparison with the alternatives. Also, R&D is measured in terms of a unit of currency, which provides a natural weighting, whereas other innovative measures are more qualitative.

A disadvantage of using R&D as the technology measure is the existence of spillovers. A firm might invest in large amounts of R&D without receiving any benefit from it, if the R&D does not produce any outputs (either in the form of innovation for the firm, or in the form of acquiring the ability to learn from other firms' innovations). There are long and unknown variable lags between the act of investing in R&D and reaping useful output from it.[5] The transmission mechanisms for knowledge to spill over from one firm to another are also poorly understood. For example, the R&D spending of Intel has dramatically affected the development of computer technologies used by other firms all over the world, but the process by which this knowledge has been absorbed by other firms is unclear, and rarely addressed in the literature.

Patents are a widely available and standard way to measure the outputs of knowledge. The problem with patents is that a large number of them appear to be of very low value and there is no obvious method of weighting them to take account of this.[6] In some countries expert innovation surveys exist, which can be viewed as a method of cutting off the lower tail of low value patents. The UK Science Policy Research Unit (SPRU) Innovation Survey is a good example of this, since industry experts were asked to list the most important innovations in their field, in order to weed out the innovations with little value. Output measures such as patents suffer from some of the problems of R&D –

such as spillovers and variable time lags – and add new problems – such as the difficulties of dealing with count data.

Diffusion measures seem to be closely related to what is usually thought of as technology. A common example would be the use of computers in a firm. Researchers are usually faced with the problem of which technologies to include: what sort of computers (word processors, mainframes); whether also to include production-based technologies (lasers, robots, NC, CADCAM); how to weight the usage (the proportion of people using the computer is a common form of weighting). The most satisfactory method seems to be constructing the capital stock of information technology (IT), although since IT is hardwired into more and more modern organisations, separating out this component becomes increasingly difficult. Measuring the diffusion of a particular technology is difficult in any time series context, since the passage of time changes the significance of using a particular type technology. For example, in 1978 an indicator of whether a computer was extensively used within the firm gave a very different signal to that same indicator in 1998. Diffusion-based measures of technology are more likely to suffer more from simultaneity problems than, say, R&D. Current changes to a firm's environment will have less of an effect on something like R&D than on the decision whether or not to postpone investing in more computers. This is primarily because of the greater adjustment costs attached to restructuring or cancelling a research programme than in purchasing a new piece of hardware.

The measurement of skills is a less controversial issue, and the problems associated with it are well known. There are two main methods of measuring skills. Perhaps the most common in the literature is to use an indicator of occupation, often simply by dividing the population into manual (production) and non-manual (non-production) workers. Such categorisations can be criticised, since many non-manual occupations require very low levels of skill. Education-based measures are more closely tied to ideas of levels of human capital, but face the problem that even highly educated workers may not be employed doing very skilful jobs. Some authors have developed measures based on job content, where an occupation is broken down into different levels of task complexity (see Wolff, 1997). In studies that have compared them, these measures all tend to be highly correlated across industries (e.g. Berman et al, 1997). Nevertheless, there are real worries that the categories chosen are not comparable over time and across countries.

Another measurement issue relates to double counting. Innovative activities tend to be labour intensive and involve skilled workers. R&D is a good example, since typically about half of all R&D is staff costs and only 10% capital costs. This will automatically generate a positive correlation between the level of skilled (i.e. better paid) employees and the level of R&D. Correcting for this ‘double counting’ has been found to be important in the productivity literature. The problem reappears here in many guises.

Finally, there are issues to be grouped under ‘selectivity’. The usual problems of sample response and survivor bias are encountered, but there are particular problems relating to the use of R&D expenditure. In most European countries, disclosure in company accounts of the amount of R&D carried out is not compulsory. This means that researchers have to be aware that excluding, or setting to zero, those companies which do not disclose any R&D is likely to introduce a selectivity bias.

4. RESULTS

The papers are divided into three topics. The first table contains papers analysing the effects of technology on the skill structure. Here we concentrate on attempts to correlate technology with the proportion of skilled workers in costs or employment shares. The second table examines the evidence of correlation between wages and technology. These could be driven by skill-biased technical change: the average wage in a plant could reflect movement in the distribution of employment of different types of workers, for example. To complete the survey we examine correlations of employment with technology.

The structure of each of the three tables is the same. Studies are divided according the level of aggregation used: first the industry level, then the level of the enterprise, and finally the individual.

4.1 Skills

There is a preponderance of studies from the U.S. in all of the tables, and in particular studies at the industry level. A key paper in this area is Berman, Bound and Griliches (1994), who estimate a version of equation (7) on 4 digit US manufacturing data in long differences. They use R&D expenditures and computer investment as their measures of technical change. These technological proxies are found to have positive and significant effects on the growth in the wage bill share of non-production workers, the computer variable accounting for about a third of the increase in the share.

Autor, Katz and Krueger extend this study over a longer time period (from the 1940s to early 1990s) and to non-manufacturing. They corroborated the importance of technical change (especially computer use) in accounting for the increase in skilled workers as a proportion of the wage bill. Machin and Van Reenen (1998) extend the U.S. results to the manufacturing sectors of 6 other countries (Denmark, France, Germany, Japan, Sweden and the UK). They find results which broadly support the importance of skill bias across all countries using their measure of R&D intensity. Other papers with country-specific analyses have also tended to find evidence of skill-biased technical change (e.g. Gera et al (1998) for Canada, Hansen (1995) for Sweden and Fitzenberger (1997) for Germany), but Goux and Maurin (1997) are more sceptical about its importance in France.

Aggregation may be a serious problem for these industry studies, so panel B considers the analyses based at the level of the enterprise. There are a greater range of countries represented in these studies, as well as a larger number of alternative proxies for technical change. The overall results still suggest the presence of skill-biased technological change. The Longitudinal Research Dataset (LRD), a manufacturing panel dataset for the population of larger plants, has been a prime resource in the USA.[7] Doms et al (1997) and Dunne et al (1997) both find evidence of skill bias, but Doms et al (1997) stress that they cannot find evidence for significant effects in the time series dimension of their data. This is a worrying result, because it does suggest that some other unmeasured factor may be driving both skills and technology. On the other hand, measurement error issues and the fact that they use counts of production technologies (rather than computer usage) might account for their results. Indeed when Doms et al (1997) use compter investment as an alternative measure they find that this is associated with the growth of skilled workers, even in the time series dimension. Haskel and Heden use the equivalent large dataset of British plants and also find evidence of a positive impact of computers on the growth of skill intensity in the two years where computer investment data is available.

Adams (1997) focuses on firms mainly operating in the chemical industry. In his careful study he finds that firm R&D in the same product field as that produced by the plant is associated with skill bias. He could not find consistent evidence for skill bias from total firm, state or industry R&D. Although Adams was able to control for detailed industry effects, he did not include plant fixed effects.

Duguet and Greenan (1997) use an innovations survey to estimate cost share equations for a panel of French manufacturing firms 1986-1991 in long differences. They find evidence for skill bias and argue that it comes primarily from the introduction of new products, although their results here are mixed. One problem with subjective innovations survey is the comparability of the notion of innovation across different firms. An interesting extension, given the increasing availability of this type of innovation survey, would be to use the longitudinal aspect of the panel when the question is asked to the same firms in future. Machin (1996) uses the British Workplace Industrial Relations Survey (WIRS) panel 1984-1990, which contains information on the introduction of computers and also finds evidence for skill bias. Aguirrebriria and Alonso-

Borrega (1997) use Spanish panel data and find effects of their measure of 'technological capital', but they find no robust effects of R&D.

We end this sub-section with three general comments. First, there does appear to be considerable support for the notion of skill-biased technical change across a range of studies, and these are usually (but not always) robust to controlling for fixed effects. Secondly, there have been few attempts to find instrumental variables to deal with the potential endogeneity of technology. Candidates could include government-induced schemes to alter the incentives to accumulate technological capital (such as R&D tax credits, government grants etc[8]).

Thirdly, there are surprisingly few studies which try to analyse the mechanisms by which technological change translates into higher demand for skills. One mechanism is through organisational changes such as delayering, decentralisation and giving greater autonomy to workers. These organisational factors have been found to be important in the case study evidence and in the literature on the productivity paradox (investigating why computers have not raised measured productivity by as much as might have been expected). Some preliminary work suggests that this organisational restructuring could be the link between technology and labour demand (Bresnahan et al. (1998); Caroli and Van Reenen (1999)).

4.2 Wages

We have included studies which examine both the level and structure of wages in Table 4.2. Interestingly, the majority of the studies here are carried out at the micro level (mainly individual). The authors of these studies have paid much more attention to the need to control for fixed effects and endogeneity.

Dickens and Katz (1987) is an early piece of work which focused on factors correlated with inter-industry wage premiums. They found that there were many observable industry level factors associated with these premiums, including R&D intensity. The rise in wage inequality prompted some additional interest in this type of work in the U.S. Inspired by the well-known analysis by Mincer (1991) of time series data, Allen (1996) calculated that the increase in the rate of return to schooling between 1979-1989 was most dramatic in industries with greater R&D intensities. This is similar to Bartel and Lichtenberg's (1990) finding that the more recent vintages of the capital stock are positively related to educational premiums.

At the enterprise level, most studies find a positive correlation of technology with wages (e.g.s. Dunne and Schmitz (1995) for the U.S., Martinez-Ros (1998) for Spain; Casavola et al (1996) for Italy; Machin et al. (1998) for the UK; Tan and Batra (1997) for Columbia, Mexico and Taiwan). There is a less clear pattern that skilled workers receive a higher premium than unskilled workers, however. More worryingly, these results are sensitive to various econometric tests. The study by Doms et al (1997) finds that their positive effects of diffusion on wages disappear in their differenced models. Chennells and Van Reenen (1997) find that instrumenting the adoption of new technologies at the plant level with industry level measures of technological opportunity reduced the effect of technology to zero.

There is a similar pattern in the individual data. Krueger (1993) found strong effects of computer use on wages. The computer-earnings correlations were significantly greater for educated workers. Similar observations have been made in other countries (e.g. Bell (1998) for the UK; Reilly (1995) in Canada), but there is much evidence that this is due to the fact that workers with higher ability are given the best technologies to use. Entorf and Kramarz (1997) emphasise that the cross-sectional association in France disappears once fixed effects have been controlled for. More cynically, DiNardo and Pischke (1997) show that the cross-sectional correlation of wages with computer use exists in the German data, but so does an equally robust correlation with pencil use.

Van Reenen (1996) finds a positive effect of technology on average wages in British companies, even after controlling for endogeneity and fixed effects. This result, however, could be due to the different type of data used. Instead of computer use, he analyses a count of major technological innovations. These generate substantial economic rents and the paper interprets the correlation as a form of sharing in the rents from new technologies. The purchase of a computer by a firm is unlikely to generate substantial rents (apart from those going to their inventors, such as Intel).

Overall, there seems evidence that the computer-wage correlation cannot be interpreted as simply the causal effect of technical change on individual or enterprise wages. More likely it reflects the fact that the best technologies are likely to be used by the most able workers who were already earning higher wages.

4.3 Employment

Finally we come to the relationship between employment and technology. There have been relatively few cross industry econometric studies of the impact of technology on total employment. Those which do exist tend to be mainly descriptive in character and focused on specific industries (e.g. Dosi and Soete, 1983). The analysis in Blechinger et al. (1998) captures some of the salient points. An examination of the OECD STAN/ANBERD database (which covers manufacturing) reveals that the high technology industries (those with higher R&D intensity) expanded more quickly (contracted less slowly) than the medium or low technology industries.

Focusing on the firm level studies, there are a wide variety of results from different countries. Overall, there appear to be consistently positive effects of proxies for product innovations on the growth of employment (e.g. Konig et al. (1995), and Entorf and Pohlmeier (1995) for German firms; Leo and Steiner (1994) for Austrian firms; Van Reenen, 1997, for British firms). The results for process innovations are very mixed – although usually insignificant, several examples of positive effects exist (e.g. Blanchflower and Burgess (1997) for UK and Australian plants; in Blechinger et al. (1998) for Dutch firms and Regev (1995) for Israeli firms). In an interesting study of French data, Greenan and Guellac (1996) find that process innovations have a strong positive effect at the firm level, but this washes out at the industry level. The story is reversed for product innovations.

When measures such as R&D are used, negative correlations frequently arise. (See Klette and Forre (1998) for Norwegian plants; Brouwer et al. (1993) for Dutch firms.) The most plausible explanation for these results is that the effects of innovation depend critically on the type of innovations being produced. Also, there is a serious concern that firms are introducing new technologies when they expect demand conditions to improve, thus biasing the coefficients on the technology proxies upwards.

In general, existing employment studies have rarely been conducted with as detailed an eye to the econometric problems involved as those investigating wages and skills. This perhaps reflects the greater theoretical ambiguity involved in estimating the relationship (and policy interest in the microeconomic results). The econometric problems are particularly difficult in these studies however, and future work needs to address these more seriously.

5. CONCLUSIONS

In any survey it is difficult to reach definitive conclusions, aside from methodological ones. Nevertheless we hazard the following stylised description of our brief survey. First, there is considerable evidence of a positive correlation of various measures of technology with the skill structure suggesting that technology is, on average, biased towards skilled labour. Secondly, there is also strong evidence of a positive correlation between wages and innovation. Thirdly, the evidence on total employment is more mixed, with some measures (diffusion-based) suggesting a positive association and others (R&D-based) being more negative.

The three main problems with these results is the presence of unobserved heterogeneity, endogeneity and measurement problems. For the (still relatively few) studies attempting to deal with fixed effects and/or endogeneity, the skills-technology correlation appears to be stronger than the wages-technology relationship. Indeed, we would go as far to say that most studies appear to find no causal effect of diffusion based measures (such as computer use) on wages. Finally, there do seem to be important differences in the results stemming from different notions of innovation. The diffusion-based measures of innovation (computer use) might have no effect on wages, but large technological innovations might have a more substantial impact. Certainly the enterprise level correlations with employment growth differed enormously depending on whether R&D or diffusion was the variable of interest.

In terms of future work, two immediate points are obvious. First we need more studies attempting to deal with the problems of the endogeneity of the technology choice by searching for better instruments that exogenously shift firms' incentives to introduce new technologies. Work on this is only beginning. Secondly, the theoretical framework for analysing these issues is still very crude. The basic neo-classical model needs to be supplemented by a richer understanding of technological adoption in a tractable manner. There are a plethora of theoretical models; the task is to translate them into an empirically coherent form for implementation and testing. In particular, examining the role of organisational change in translating the effects of technology into labour demands should be a key area of future research (Caroli (1998)). Finally, although we welcome the constant quest for new indicators, one of the key concerns is to achieve stability and comparability in the time series measures of technology.

Appendix I

The micro-economics of technology and employment : a simple example

A special case of the translog cost function is when there is a constant elasticity of substitution between the factors (the translog allows for more general patterns of substitution and complementarity). To simplify the discussion we will work with this form. Write the production relationship as:

$$VA = T[(AN)^{(\sigma-1)/\sigma} + (BK)^{(\sigma-1)/\sigma}]^{\sigma/(\sigma-1)}$$

(A1)

Where K = capital, N = labour, VA = value added. T represents a neutral technology parameter, A is labour augmenting technology and B is capital augmenting technology. If a firm maximises profit then the labour demand equation is:

$$\log N = \log VA - \sigma \log(W/P) + (\sigma - 1)\log A$$

(A2)

The elasticity of labour demand with respect to a change in labour augmenting technical progress is given by:

$$\frac{\partial \log N}{\partial \log A} = \left[\frac{\partial \log VA}{\partial \log P}\right]\left[\frac{\partial \log P}{\partial \log MC}\right]\left[\frac{\partial \log MC}{\partial \log A}\right] + (\sigma - 1)$$

(A3)

or more succinctly,

$$\frac{\partial \log N}{\partial \log A} = \eta_P \mu \theta + (\sigma - 1)$$

(A4)

where the effect of technical change on labour demand is now written as a function of four factors: the price elasticity of product demand[9] (η_p), the mark-elasticity (a measure of market power, μ), the 'size' of the innovation as measured by its effect on marginal cost (θ) and the elasticity of substitution between capital and labour (σ) .

The interpretation of all of these results is quite intuitive and discussed in the text. Some points to note are that:

- When there is perfect competition (θ =1), and no substitution between labour and capital (e.g. if labour is only factor of production σ = 0) then for a normalised innovation (θ =1) the effect on labour demand will hinge on whether demand is elastic. If product demand is elastic ($\eta_p>1$) then employment will rise, if it is inelastic ($\eta_p<1$) then employment will fall.

- Since it is difficult to know the effect of any given measure of innovation on marginal cost, it is very difficult to compare different studies to determine the quantitative effect of an innovation – there is no natural scale of normalisation.

For further discussion of these points see Van Reenen (1997).

Endnotes

(1) A good survey and an interpretation of the case study evidence are given by Attewell (1987, 1990). As expected the evidence is highly mixed, with the exact effect of technology on skills being highly dependent upon the particular context.

(2) This section owes much to the exposition in Adams (1997).

(3) This roughly corresponds to the Schumpeterian triptych of invention, innovation and diffusion.

(4) In OECD statistics most countries follow the guidelines of the Frascati manual (1993). Within countries accounting regulations often define how R&D is to be reported (e.g. in the USA under FAS and in the UK under SSAP13(Revised)).

(5) Of course the same is true of the standard way in which the physical capital stock is measured. The main difference here is that the degree of uncertainty involved with R&D investments is much greater, and there is usually a method of benchmarking the physical capital stock in a particular year.

(6) Some current ideas include renewal fees, number of countries where the patent is registered, surveys of inventors and citations.

(7) Note that similar datasets are also available in European countries, but confidentiality clauses restrict general access to them.

(8) The Machin and Van Reenen (1998) study investigates the sensitivity of their results to instrumenting total R&D with government-financed R&D.

(9) We are assuming the elasticity between value added and output is unity.

References

Adams, J. (1997) ‘The structure of firm R&D and the factor intensity of production’, NBER Working Paper 6099 (forthcoming in *Review of Economics and Statistics*).

Aguirregabriria, V. and Alonso-Borrega, C. (1997) ‘Employment occupational structure, technological capital and reorganisation of production’, Universidad Carlos III de Madrid Working Paper 97-12.

Allen, S. (1996) ‘Technology and the wage structure’, NBER Working Paper 5534 (forthcoming in *Journal of Labor Economics*).

Arabsheibani, G., Enami, J. and Marin A. (1996) ‘The impact of computer use on earnings in the UK’, Royal Holloway College, University of London mimeo.

Attewell, P. (1987) ‘The de-skilling controversy’, *Work and Occupations*, 14(3), 323-346.

Attewell, P. (1990) ‘What is skill?’, *Work and Occupations*, 17(4), 422-448.

Autor, D., Katz, L. and Krueger, A. (1998) ‘Computing inequality: have computers changed the labor market?’, *Quarterly Journal of Economics*, 113(4), 1169-1213.

Bartel, A. and Lichtenberg, F. (1987) ‘The comparative advantage of educated workers in implementing new technology’, *Review of Economics and Statistics*, 69(1), 1-11.

Bartel, A. and Lichtenberg, F. (1991) ‘The age of technology and its impact on employee wages’, *Economics of Innovation and New Technology*, 1, 215-31.

Bartel, A. and Sicherman, N. (1998) ‘Technological change and the skill acquisition of young workers’, *Journal of Labor Economics*, 16(4), 718-755.

Bartel, A. and Sicherman, N. (1999) ‘Technological change and wages: an inter-industry analysis’, *Journal of Political Economy*, 107(2), 285-325.

Bell (1998) ‘Skill-biased technical change and wages: evidence from a longitudinal data set’, forthcoming in *Industrial and Labour Relations Review*.

Bellman, L. and Boeri, A. (1995) National Academy of Science Conference Proceedings, May.

Berman, E., Bound, J. and Griliches, Z. (1994) 'Changes in the demand for skilled labor within US manufacturing industries', *Quarterly Journal of Economics*, 109(2), 367-97.

Berndt, E., Morrison, C. and Rosenblum, L. (1992) 'High-tech capital formation and labor composition in US manufacturing industries: an exploratory analysis', NBER Working Paper 4010.

Bernstein, J. and Mishel, L. (1996) 'Did technology's impact accelerate in the 1980s?' Economic Policy Institute mimeo.

Betts, J. (1997) 'The skill bias of technological change in Canadian manufacturing industries', *Review of Economics and Statistics*, 79(1), 146-50.

Blanchflower, D., Millward, N. and Oswald, A. (1991) 'Unionisation and employment behaviour', *Economic Journal*, 101, 815-34.

Blanchflower, D. and Burgess, S. (1999) 'New technology and jobs: comparative evidence from a two country study', *Economics of Innovation and New Technology*, 6(1/2), forthcoming.

Blechinger, D., Kleinknecht, A., Licht, G., and Pfeiffer, F. (1998) 'The Impact of Innovation on Employment in Europe: An Analysis using CIS Data', ZEW Dokumentation Nr. 98-02.

Braverman, H. (1974) *Labor and Monopoly Capital: The degradation of work in the Twentieth Century*, New York: Monthly Review.

Bresnahan, T. (1997) 'Computerisation and wage dispersion: an analytical reinterpretation', Stanford University Working Paper 97-031.

Bresnahan, T., Brynjolfsson, E. and Hitt, L. (1998) 'Information technology, work organisation and the demand for skilled labor: firm-level evidence', Massachusetts Institute of Technology Industrial Performance Centre Working Paper 98-010.

Buckberg, E. and Thomas, A. (1996) 'Wage dispersion in the 1980s: resurrecting the role of trade through the effects of durable employment changes', *IMF Staff Papers*, 43(2), 336-354.

Brouwer, E., Kleinknecht, A. and Reijnen, J. (1993) 'Employment growth and innovation at the firm level: an empirical study', *Journal of Evolutionary Economics*, 3, 153-159.

Card, D., Kramarz, F. and Lemieux, T. (1996) ‘Changes in the relative structure of wages and employment: a comparison of the U.S., Canada and France’, NBER Working Paper 5487.

Caroli, E. and Van Reenen, J. (1999) `Skills and organisational change: evidence from British and French establishments in the 1980s and 1990s’, mimeo Institute for Fiscal Studies, London.

Casavola, P., Gavosto, P. and Sestito, P. (1996) ‘Technical progress and wage dispersion in Italy: evidence from firms’ data’, *Annales d’Economie et de Statistique*, Jan-June 1996, 387-412.

Chennells, L. and Van Reenen, J. (1997) ‘Technical change and earnings in the British establishment’, *Economica*, 64(256), 587-604.

Davis, S. and Haltiwanger, J. (1991) ‘Wage dispersion between and within US manufacturing plants, 1963-86’, Brookings Papers: Microeconomics 1991.

DiNardo, J. and Pischke, J.S. (1997) ‘The returns to computer use revisited: have pencils changed the wage structure too?’ *Quarterly Journal of Economics*, 112(1), 291-303.

Dickens, W. and Katz, L. (1987) 'Inter-industry wage differences and industry characteristics', in Lang, K. and Leonard, J. (eds.) *Unemployment and the structure of labour markets*, New York: Basic Books.

Doms, M., Dunne, T. and Roberts, M. (1994) 'The role of technology use in the survival and growth of manufacturing plants', mimeo, Centre for Economic Studies, US Bureau of the Census.

Doms, M., Dunne, T. and Troske, K. (1997) 'Workers, Wages and Technology', *Quarterly Journal of Economics*, 112(1), 253-289.

Duguet, E. and Greenan, N. (1997) 'Skill biased technological change: an econometric study at the firm level', CREST Working Paper.

Dunne, T., Haltiwanger, J. and Troske, K. (1997) 'Technology and jobs: secular changes and cyclical dynamics', Carnegie-Rochester Conference Series on Public Policy, 46(0), 107-78.

Dunne, T. and Schmitz, J. (1995) 'Wages, employment structure and the employer size-wage premia: their relationship to advanced technology usage at US manufacturing establishments', *Economica*, 62, 89-108.

Edwards, R., (1979) *Contested Terrain: the transformation of the workplace in the twentieth century*, New York: Basic Books.

Entorf, H., Gollac, M. and Kramarz, F. (1999) 'New technologies, wages and worker selection', *Journal of Labor Economics*, 17(3), 464-491.

Entorf, H. and Kramarz, F. (1997) 'Does unmeasured ability explain the higher wages of new technology workers?', *European Economic Review*, 41(8), 1489-1509.

Entorf, H. and Kramarz, F. (1998) 'The impact of new technologies on wages and skills: lessons from matching data on employees and their firms', *Economics of Innovation and New Technology,* 5, 165-197.

Entorf, H. and Pohlmeir, W.(1991) 'Employment, innovation and export activity', in Florens, J. et al. (eds.) *Microeconometrics: surveys and applications*, Oxford: Basil Blackwell.

FitzRoy, F. and Funke, M. (1995) `Skills, wages and employment in East and West Germany', International Monetary Fund Working Paper WP/95/4.

Garen, J. (1994) `Executive compensation and principal-agent theory', *Journal of Political Economy,* 102(6), 1175-1199.

Gera, S., Gu, W. and Lin, Z (1998) `Technology and the demand for skills: an industry-level analysis', mimeo Statistics Canada.

Goldin, C. and Katz, L. (1996) 'Technology, skill and the wage structure: insights from the past', *American Economic Review,* 86, May, 252-57.

Goux, N. and Maurin, E. (1997) 'The decline in demand for unskilled labour: an empirical analysis method and its application to France', CREST mimeo.

Greenan, N. and Guellec, D. (1997) 'Technological innovation and employment reallocation', INSEE mimeo.

Greenan, N., Mairesse, J. and Topiol-Bensaid, A. (1998) 'Information Technology and R&D impacts on productivity and skills: a comparison on French firm level data', mimeo, INSEE.

Hansson, P. (1997) 'Trade, technology and changes in employment of skilled labour in Swedish manufacturing', in J. Fagerberg, P. Hansson, L. Lundberg and A. Melchior (eds.) *Technology and International Trade*, Cheltenham: Edward Elgar Publishing.

Haskel, J. and Heden, Y. (1997) 'Computers and the demand for skilled labour: panel evidence for the UK', *Economic Journal Conference Proceedings*, 109, C68-C79.

Hildreth, A. (1998) 'Rent sharing and wages: product demand or technology driven wage premia?', *Economics of Innovation and New Technology*, 5.

Holthausen, R., Larcker, D., and Sloan, R. (1995) 'Business unit innovation and the structure of executive compensation', *Journal of Accounting and Economics*, 19(2-3), 279-313.

Jackman, R., Layard, R., Manacorda, M., and Petrongolo, B. (1996) 'European vs. US unemployment: different responses to the same shock?', LSE Centre for Economic Performance Discussion Paper 349.

Kaiser, U. (1998) 'The Impact of New Technologies on the demand for heterogeneous labour', Centre for European Economic Research (ZEW) Working Paper 98-26.

Kaldor, N. (1932) ‘A case against technical progress’, *Economica,* May, 180-196.

Katsoulacos, Y. (1986) *The Employment Effect of Technical Change*, Oxford: OUP.

Klette, T. and Førre, S. (1998) `Innovation and job creation in a small open economy: evidence from Norwegian manufacturing plants 1982-92’, *Economics of Innovation and New Technology,* 5, 247-272.

Konig, H., Buscher, H., and Licht, G. (1995) ‘Employment, investment and innovation at the firm level’, in *The OECD jobs study: evidence and explanations*, Paris: Organisation for Economic Co-operation and Development.

Krueger, A. (1993) ‘How have computers changed the wage structure: evidence from micro data, 1984-89’, *Quarterly Journal of Economics*, 108(1), 33-61.

Krugman, P. (1994) ‘Past and prospective causes of high unemployment’, *Federal Reserve Bank of Kansas City Economic Review*, Third Quarter, 23-43.

Leo, H. and Steiner, V. (1994) *Innovation and employment at the firm level*, Wien: Osterreichisches Institut fur Wirsschaftsforschung.

Loh, E. (1992) ‘Technological changes, training and the inter-industry wage structure’, *Quarterly Review of Economics and Finance*, 32(4), 26-44.

Lynch, L. and Osterman, P. (1989) ‘Technological innovation and employment in telecommunnications’, *Industrial Relations*, 28(2), 188-205.

Machin, S. (1996) ‘Changes in the relative demand for skills in the UK labour market’, in Booth, A. and Snower, D. (eds.), *Acquiring skills*, Cambridge: Cambridge University Press.

Machin, S., Menezes-Filho, N. and Van Reenen, J. (1998) ‘R&D, pay and performance: evidence from UK firms’, IFS mimeo.

Machin, S. and Van Reenen, J. (1996) ‘The impact of R&D knowledge accumulation on wages: evidence from European corporations’, in Belcher, A. et al. (eds.) *R&D decisions: strategy, policy and disclosure*, London: Routledge.

Machin, S. and Van Reenen, J. (1998) ‘Technology and changes in skill structure: evidence from seven OECD countries’, Berkeley Centre for Labour Economics Working Paper No. 3.

Manacorda, M. and Manning, A. (1997) ‘Just can't get enough: more on skill biased change and unemployment’, LSE Centre for Economic Performance Discussion Paper 412.

Martinez-Ros, E. (1998) ‘Real wages and innovations in Spanish manufacturing firms’ mimeo, Universitat Autonoma de Barcelona.

Mincer, J. (1991) ‘Human capital, technology, and the wage structure: what do time series show?’, NBER Working Paper 3581.

Nickell, S. and Bell, B. (1995) ‘The collapse in the demand for the unskilled and unemployment across the OECD’, *Oxford Review of Economic Policy*, 11(1), 40-62.

Nickell, S. and Kong, P. (1987) ‘Technical progress and jobs’, LSE Centre for Labour Economics Discussion Paper 336.

Nickell, S., Vainiomäki, J., and Wadhwani, S. (1994) ‘Wage and product market power’, *Economica*, 61, 457-474.

OECD (1994) *The Jobs Study* OECD: Paris

Osterman, P. (1986) ‘The effect of computers on the employment of clerks and managers’, *Industrial and Labour Relations Review*, 39(2), 175-85.

Regev, H. (1998) ‘Innovation, skilled labour, technology and performance in Israeli industrial firms’, *Economics of Innovation and New Technology*, 6(1/2), forthcoming.

Reilly, K. (1995) ‘Human capital and information: the employer size-wage effect’, *Journal of Human Resources*, XXX (Winter), 1-18.

Ross, D. R. and Zimmerman, K. (1993) ‘Evaluating reported determinants of labour demand’, *Labour Economics*, 1, 71-84.

Smolny, W. (1998) ‘Innovations, prices and employment: a theoretical model and empirical application for West German manufacturing firms’ Journal of Industrial Economics, XLVI(3), 359-382.

Solow, R. (1966) Wiskell Lectures.

Siegel, D. (1998) ‘The impact of technological change on employment and wages: evidence from a firm-level survey of Long Island manufacturers’, *Economics of Innovation and New Technology*, 5(2), 227-246.

Soete, L. and Dosi, G. (1983) *Technology and Employment in the Electronics Industry*, London: Francis Pinter.

Tan, H. and Batra, G. (1997) ‘Technology and firm size-wage differentials in Colombia, Mexico, and Taiwan (China)’, *The World Bank Economic Review*, 11(1), 59-83.

Troske, K. (1999) `Evidence on the employer size-wage premium from worker-establishment matched data’, *Review of Economics and Statistics,* 81(1), 15-26.

Vainiomäki, J. (1998) `Technology, skills and wages: results from linked worker-plant data for Finnish manufacturing’, University of Tampere mimeo.

Van Reenen, J. (1996) ‘The creation and capture of economic rents: wages and innovation in a panel of UK companies’, *Quarterly Journal of Economics*, CXI, 443, 195-226.

Van Reenen, J. (1997) ‘Technological innovation and employment in a panel of British manufacturing firms’, *Journal of Labor Economics* , 15(2), 255-284.

Wolff, E. (1996) `Technology and the demand for skills’, *STI - Science, Technology Industry Review,* France: OECD.

Zimmerman, K. (1991) ‘The employment consequences of technological advance: demand and labour costs in 16 German Industries’, *Empirical Economics*, 16, 253-266.

Table 4.1: The effect of technology on skill structure

A. Industry level					
Study	Method	Data	Proxy for technology	Controls	Result
Autor, Katz and Krueger (1998)	Mainly long-differenced changes in skilled share of wage bill regressions (education and occupation)	1960-70, 1970-80 (Census); 1980-90, 1990-95 (CPS); 149 U.S. industries (manufacturing and non-manufacturing)	Computer use in 1984, 1984-93 change in computer use; R&D; TFP	Initial education level; capital, output, imports, exports, outsourcing	High tech industries have faster upgrading of skills; effect has grown stronger over time (bigger in 1970s and 1980s)
Bartel and Lichtenberg (1987)	Estimation of restricted variable cost function	61 manufacturing industries in 1960, 1970, 1980	Proxies for age of capital stock	Age, education, gender cells	Positive association of younger capital with skill proportion
Bartel and Sicherman (1998)	Effects of industry technology on individual training	National Longitudinal Survey of Youth in manufacturing industries 1987-92; males 14-21 in 1979	Cross sectional industry level measures of computer investment, TFP, R&D intensity; introduction of new production processes, patents used	Schooling dummies, experience, race, MSA, part-time, gender, tenure, firm size, marital status, union, time dummies, industry level union coverage, unemployment, job creation and destruction	Workers more likely to get training as technological progress increases. More educated workers are more likely to get training but this 'education-training gap' narrows as rate of technological progress increases
Berman, Bound and Griliches (1994)	Change in proportion of non-production workers in wage bill and employment	ASM: 4 digit manufacturing industries 1979-89	R&D intensity, computer investment	Fixed capital, value added, time dummies	Positive association of technology proxies with changing skill %
Berndt, Morrison and Rosenblum (1992)	Within Groups estimates of proportion of total hours of a skill group regressed against various capital intensities; also by industry separately	2 digit US SIC manufacturing 1968-86 merging BEA, BLS and CPS	High tech office and information equipment as proportion of total industry capital stock (OF/K).	Blue collar/white collar; education cells for production and non-production workers	Positive effect of high tech capital on white collar hours; within blue-collar occupations evidence of educational upgrading, less clear within WC occupations (middle education groups lose out most)
Gera, Gu and Lin (1998)	Within Groups estimates of wage bill and employment shares of (a) higher occupational groups; (b) knowledge	29 Canadian industries in mfng and non-mnfg; 1981-1994: 1981 (Survey of Work History), 1986-1990 (Labor market	R&D stock; patent stock;age of capital stock; log of TFP	Capital, output, time trend	All technology variables tend to be significant except for TFP

	workers (Wolff-Baumol)	activity survey); 1993-94 (Survey of Labor and Income Dynamics);			
Goldin and Katz (1996)	Wage bill share of non-production workers	1909-19; 1959-69; 1969-79; 1979-89 U.S. Census of Manufactures: 450 inds (256 in 1909-19)	Capital	Output	Positive effect of capital-output ratio in all years
Goux and Maurin (1996)	Wage bill share of higher and lower grade professionals, administrators and officials; regress industry fixed effects against technology measures	35 French industries (all sectors) 1982-93	Computer use, industrial technologies (e.g. robots, NC machine tools, telewatching)	Capital, output, time dummies	Industry fixed effects positively correlated with computer use, but negatively correlated with 'industrial technologies'
Hansson (1997)	Change in proportion of educated workers in employment and wage bill regressions	16 Swedish manufacturing industries; 2 long differences 1970-85; 1985-90	R&D intensity; share of technicians	K, Y, time dummy	Both technology measures have positive and significant effects
Machin and Van Reenen (1998)	Changes in wage bill (and employment) share of skilled employees (occupation and education)	1970-89; 2 digit manufacturing industries in Denmark, France, Germany, Japan, Sweden, UK, US (15)	R&D intensity	Capital, value added, time dummies, imports (OECD and non-OECD)	Skill upgrading faster in high R&D industries in all countries
Mishel and Bernstein (1997)	Change in share of 5 educational groups	34 industries in three periods (1973-79, 1979-89, 1989-94); CPS with 1990 PUMS; BEA, NIPA	Computer and capital equipment, share of scientists and engineers	Dummy for computer industry; physical capital	Positive effect but no change over time in coefficients
Osterman (1986)	Change in employment after computer installations	20 industries; 1972, 1978	Total amount of main computer memory in industry	Total employment of clerks, non-data entry clerks, managers and others	Computers associated with falls in employment of clerks AND managers (although LR effects of managers much smaller)
Wolff (1996)	Three skill variables: SC (substantive complexity), IS (interactive skills) and MS (complexity skills), rated for 12,000 jobs; follow occupations by ind	43 U.S. manufacturing industries; 1970-80; 1980-90	TFP; computing investment; R&D; % computer workers and engineers; K/L growth	Capital-output ratio; time dummies, union, imports, exports.	Positive relation of R&D and computers to growth of SC and IS

Table 4.1 cont.: The effect of technology on skill structure

B. Enterprise level					
Study	Method	Data	Proxy for technology	Controls	Result
Adams (1997)	2 factor cost shares (white collar and blue collar labour, materials equation dropped); R&D (t-1) exogenous. In cost share equations, SUR; symmetry and homotheticity imposed; no enterprise fixed effects	US chemical firms with positive R&D for 5+ years; combine with plant level data on production (LRD); 1976-88; 9,500 observations	Firm R&D broken down also by NSF applied product field and state; state-wide and industry-wide applied product R&D spillover pools also created	Relative factor prices (industry-state); K, number of plants in firm; industry (in share equation) and time dummies, dummy for plant slowdown, plant birth, spillovers	Firm R&D has a positive effect on both labour shares; only consistent effect of firm R&D in same product field as plant; mixed results on spillovers
Aguirregabriria and Alonso-Borrega (1997)	Factor demand equations for 5 types of labour, and 3 types of capital (total, R&D, bought-in technology); first differences; GMM; attempts to control for selectivity through propensity matching	CBBE; Balanced panel of 1,080 Spanish manufacturing firms 1986-91	R&D, expenditure on technological capital - “successful innovations generated externally to the firm”	Output, capacity utilisation, white collar-blue collar wage differential, time dummies	No effect of R&D and stock of technological capital has an unskilled bias; but dummy for introduction of ‘technological capital’ has strong negative effects on blue collar workers; most change in downturns
Bresnahan, Brynjolfsson and Hitt (1998)	I Human capital acquisition equations, similar to Autor et al., including IT and physical capital controls; II IT demand equations, controlling for skills make-up and organisation measures	IT information for the Fortune 1000, 1987-94; survey of workplace organisation on c. 380 firms, 1995-96; Compustat data	IT capital stock, MIPs (measure of computing capacity), number of PCs	I Decentralisation, industry dummies, changes in IT and capital per worker, in capital as a share of output, and in output; II skill, college proportions, workforce organisation, sector, year and occupation dummies	IT combined with organisational change increases relative demand for skilled workers, more so than IT alone. Output increases greater when increased IT occurs in firms with highly skilled workers and/or decentralised organisation
Caroli and Van Reenen (1999)	OLS regressions of change in share of skilled workers	(a) 402 British establishments from WIRS panel 1984-1990; 6 occupational groups (b) 992 French establishments Enquete Reponse 1992-1996; 5	(a) % of workers affected by micro-electronic, computer intro, industry level computer use (b) computer use	(a)organizational change, total employment growth, 1984 plant characteristics (b) org change (delayer), total emp growth, 1992 plant characteristics	(a) technology significant effects (negative effect on least skilled and positive effect on most skilled); OC has negative signif effect on least skilled (b) no effect of

		occupational groups			technology in panel (but some in cross section); OC has signif negative effects on least skilled
Doms, Dunne and Troske (1997)	OLS regressions in cross section and time series; LHS includes %skills (education and occupation); wages by skill group; growth regressed on 1993 characteristics and changes 1988-93	US plants in SIC 34-38; 1988 and 1993 Survey of Manufacturing Technology (SMT); Worker-Establishment Characteristics Database in 1988 and 1993 (WECD=LRD+ Census); 353 plants in 1988; c.3260 in changes; also ASM	5 dummies for numbers of different types of manufacturing technologies used in plant (e.g. CAD, NC, robots, lasers, networks, automatic systems); computer investment	Capital-output ratio, total employment, age, 2 digit industry & regional dummies; MSA dummy	In the cross section technology measures associated with higher proportion of skilled workers and higher wages; in panel +ve effect of computer investment but no effect of manufacturing technologies
Duguet and Greenan (1997)	I Probits of long-differenced innovations data (for five types of innovation); II Trans-log cost share equations in long-differences	Panel of 4,954 French manufacturing firms, 1986 and 1991	Five types of innovation: product improvement; new product; product imitation; process breakthrough; and process improvement	I Firm size, market share, diversification, industry dummies, cost shares of 'conception' and 'execution' workers; II Both types of workers, capital, production volume	Skill bias in favour of 'conception' labour, and 'execution' labour a stronger substitute for capital. Reduction in demand for execution labour largely due to new product innovation
Greenan, Mairesse and Topiol-Bensaid (1998)	Essentially cross sectional and 4 year differences of the occupational structure (aggregated into 4 groups)	c. 11,000 observations on French firm-years in three time periods (1986, 1990, 1996) - whole economy; from combining ESE, BIC; correct for double counting using measure (b) (see right)	(a) IT capital from firms balance sheet: basically office and computing (inc. photocopying equipment, etc); (b) use numbers of IT workers - computer staff/electronics specialists/research staff/analysis staff	Capital, value added, sector dummies	Strong correlations in cross section, but only the negative effect of IT on lowest skilled group robust in time series
Dunne, Haltiwanger and Troske (1996)	Change in non-production workers wage bill share and employment share; short and long differences; OLS and GMM; pooled and by 2 digit industry	US manufacturing plants - LRD 1972-88; approx. 1,820 plants in SMT/LRD merged data; 11,000+ in larger data set	Change in R&D stock; dummy for adoption of (a) IT (b) production technologies (1988 SMT - 17 types of new technology)	Equipment, structures, ownership, industry, dummies for regions, time, region*time	R&D significant and positive, quantitatively important. In accounting for secular change in skill share; IT also +ve; production technologies negatively correlated (latter results not robust)

Kaiser (1998)	Ordered probit for expected net employment change (3 categories) for 4 groups of skills 1995-1997	German firms in 'business related service industries' 1995; 1059 firms	IT investment as a share of total investment	Total investment per capital, number of employees in each skill group, sales, credit rationing, export status	Positive and significant effect on most skilled group; negative and significant effect on least skilled group.
Lynch and Osterman (1989)	Labour demand regressions for 10 occupational groups	1 company (Bell telephone company) 1980-85; year-state-occupation cells	Change in technology of office switching equipment		Positive for technical and professional employees
Machin (1996)	Employment change for 6 occupational groups	UK WIRS panel data 1984-90; 402 plants; all industries	Introduction of any computers between 1984 and 1990	Dummy for fall in total employment, any manuals 1984	Positive for most skilled groups (managers and technicians) and negative for least skilled group (unskilled manuals)
Siegel (1998)	Employment share and wage bill share regressions	79 Long Island (USA) manufacturing firms; 1987-90; 6 skill groups	Introduction of various kinds of manufacturing technologies, R&D intensity	Age, size	Positive effects of skill composition
Vainiomäki (1998)	Wage bill and employment share regressions of non-production workers and educational groups; long diffs 1985-90; 1990-94	Finnish mnfg establishments (sample size varies from c.500-c.1300 plants;) 1985-1994; Census of Manufacturing; linked employee data; SMCT; R&D Surveys	(R&D/Sales) in levels and changes; introduction of advanced mnfg technology in 1990; computer investment 1990	Export share, capital, output, industrial outsourcing, ownership, industry and regional dummies	Change in R&D intensity has positive effects on wage bill share; other measures have unstable effects across different specifications

Table 4.2: The effect of technology on wages

A. Industry level					
Study	Method	Data	Proxy for technology	Controls	Result
Allen (1996)	I Wage equation by industry; regress levels and changes of coefficients against industry tech II 32 education-experience-gender cells regressed against industry dummies; dummies regressed against tech	Individual level data from US CPS in 1979 and 1989 combined with industry level data on technology (about 39 manufacturing and non-manufacturing industries)	R&D intensity, growth in capital-labour ratio; age of capital; TFP; % of scientists and engineers	Education, experience, part-time, gender, race, SMSA	Levels and changes in returns to schooling and education significantly related to R&D, high tech capital, K/L acceleration.
Bartel and Lichtenberg (1991)	Pooled cross industry wage equations (sometimes control for industry fixed effects)	1960, 1970, 1980 U.S. CPS; manufacturing; 70 age-education-gender cells by industry (35)	Age of equipment; computing investment/output; R&D to sales	Union, plant age, year dummies, K/L, output growth, profits	Younger technologies have higher wages; larger educational premium in industries using younger technology
Bartel and Sicherman (1999)	Effects of industry technology on individual earnings and educational premium	National Longitudinal Survey of Youth (NLSY) in manufacturing industries 1979 and 1993 14-21 in 1979; approx 50 industries	Cross-sectional industry level measures of computer investment, TFP; % scientists and engineers; R&D intensity; introduction of new production processes, patents used	ATQT score, Schooling dummies, experience, race, MSA, part-time, gender, tenure, firm size, marital status, union, time dummies, industry union coverage, unemployment, job creation and destruction	Positive effect on earning and earnings premium of technical change; severely reduced in fixed effects estimation ; argue that premia is due to sorting of high ability workers into high tech industries
Dickens and Katz (1987)	Individual wage equations and industry dummies; regress dummies against industry variables	1983 US CPS and industry level measures of technology	R&D intensity	Education, experience, part-time, gender, race, SMSA	Positive impact of R&D, especially for non-union workers

Table 4.2 contd.: The effect of technology on wages

B. Enterprise level					
Study	Method	Data	Proxy for technology	Controls	Result
Chennells and Van Reenen (1997)	Simultaneous system of wage and technology equations; earnings for skilled, semi-skilled and unskilled manuals	c. 900 British plants in 1984 and 1990 Workplace Industrial Relations Surveys (WIRS); 100 plant panel.	Introduction of micro electronic technologies affecting manual workers (ATC); computer presence	Lagged size, union, single site, part-time, female, % manual, foreign, industry dummies. Gender and industry wages, IV plant wages; industry R&D and patents, IV for ATC	OLS gives significant technology effects on wages; but disappears in IV results; in IV results get an effect of higher wages on technology adoption
Casavola, Gavosto and Sestito (1996)	Average wages of (a) blue collar workers and (b) white collar workers; cross sectional regressions for each year	Private sector Italian firms (over 20,000 per year) 1986-90; INPS	The share of intangible capital in total capital relative to industry average (includes patents, software and advertising)	Age, size, share of white collar workers, sales/L, value added/L, K/L, returns on investment, profits, severance fund/L, inventories, interest payments, growth of K, depreciation; industry (3 digit) and regional dummies	About 2-6% increase in wages for each group associated with technology measure
Doms, Dunne and Troske (1997)	See Table 4.1.B above	See Table 4.1.B above	See Table 4.1.B above	See Table 4.1.B above	In cross section positive effects on wages, but zero effect in the panel, regardless of measure of technology used.
Dunne and Schmitz (1995)	Average wages of non-production, production workers and share of non-production workers, as a function of plant characteristics	Cross section of 6,909 US plants in 1988, from the Survey of Manufacturing Technology, matched to Census of Manufactures data from 1987	Use of advanced computer-based machinery, nature of manufacturing at plant, average product price	Firm size, industry and regional dummies, multi-plant indicator, age of plant, number of products produced	Plants using advanced technologies pay highest wages and employ largest proportion of skilled workers. Technology use reduces size-wage premiums up to 60%
Garen (1994)	Salary equation; interactions of pay-performance sensitivity with industry R&D (as proxy for risk)	Cross section of 415 US corporations, detailed CEO remuneration info	Industry average R&D	Total firm assets, beta, age, industry dummies	Positive and weakly significant effect of R&D on salary
Holthausen, Larcker and Sloan (1995)	Regress ratio of ‘long term compensation’ (e.g.	1982-84 confidential survey of divisional CEO	1987-90 industry patents from CHI	Market share, sales, industry union,	Weak positive effect of patents on proportion

	stock options) to total compensation against future industry patents	compensation in U.S.		Herfindahl index, industry dummies	long term and total compensation
Machin, Menezes-Filho and Van Reenen (1998)	Four equations: average wages; directors pay, productivity and R&D disclosure; quasi-differenced GMM	UK Datastream companies 1983-94; 660 firms, unbalanced panel	Lagged R&D per worker	Capital, employment, time dummies, fixed effects	R&D-earnings elasticity significant for workers and directors; directors' wage-R&D elasticity twice that of workers
Machin and Van Reenen (1996)	Average wage as function of lagged R&D per worker; controls for R&D disclosure selectivity; individual effects	Global Vantage firms from Italy, France, Britain and Germany; 1982-90	Lagged R&D per worker	Capital-labour, time dummies, fixed effects, average industry wage	Positive effects, even after controlling for selectivity and fixed effects; strongest in UK and Germany.
Martinez-Ros (1998)	Arellano-Bover (1995) IV procedure	Spanish panel data; 1,306 manufacturing firms, 1990-94	Firms surveyed on process and product innovation	Lagged wage, industry wage, market share, initial skills	Significant positive effect when firms do both product and process
Tan and Batra (1997)	Size-wage differentials for investing and non-investing firms	500 firms in Columbia (1992), 5,070 in Mexico (1992), and 8,408 in Taiwan (1986)	Investment in R&D and know-how, exports and/or formal workplace training	Foreign ownership, firm age, single or multiple plant, industry dummies	Large positive effects of R&D and training for skilled workers, smaller or zero effects for unskilled
Vainiomäki (1998)	Wage regressions by skill group (prod vs. nonprod; educational group)	Unbalanced panel of Finnish establishments - see Table 4.1.B above	R&D, AMT, computers – see Table 4.1.B above	Export share, capital, output, industrial outsourcing, ownership, industry and regional dummies	Technology-wage correlation unrobust: driven out by conditioning on worker characteristics or looking at changes
Van Reenen (1996)	Average firm wage regressions (first differenced GMM) - distributed lag of innovations	Unbalanced panel of 598 UK quoted firms 1976-82	Count of major innovations (SPRU) at firm and industry level; firm level patents (taken in U.S.)	Lagged wage, market share, capital-labour ratio, industry wages, industry unemployment, industry R&D, time dummies	Innovations have positive significant effect on average wages; no additional effect of patents; interpreted as a rent-sharing

Table 4.2 contd.: The effect of technology on wages

C. Individual level					
Study	Method	Data	Proxy for technology	Controls	Result
Arabsheibani, Enami and Marin (1996)	OLS wage regressions; selectivity adjusted (but no exclusion restrictions)	British Social Attitudes Survey	Computer use		Positive effect but no different for skilled than unskilled workers
Bell (1998)	Wage growth regressions between ages 23-33	British National Child Development Survey (all individuals born in March 1958), final sample about 1000	Use of computer age 33 (1991) - no information on 1981 computer use	Ability as measured by reading and maths scores	Computer effect robust to controls for ability
Card, Kramarz and Lemieux (1996)	Changes in (a) employment-population ratio; (b) average wages in a cell regressed against computer use % in cell; separately for men and women; WLS	Age-education cells; adult whites; in US 225 cells (CPS: 1979 and 1989); in France 70 cells (EE: 1982 and 1989), in Canada 29 cells (1981 (SWH), 1988 (LMAS))	Computer usage by cell; US 1989 (CPS); France 1991 (EE); Canada 1989 (GSS)	Change in population share; initial wage instead of computer use as index of demand shock	Wages: significant positive in U.S.; insignificant in Canada; significant negative in France. Jobs: strong positive in US, insignificant in other countries.
DiNardo and Pishcke (1997)	OLS earnings functions with dummy for computer use interaction with education	German Qualification and Career Survey 1979, 1985-86, 1991-92; c. 60,000 individuals	Use of computers, pencils, hand tools, telephones, and other tools	Years of schooling, experience, part-time, city, gender, married, civil servants; detailed occupation (up to 1000)	12-18% premium in Germany; increasing over time; but also effects for other tools like pencils (which are stable over time). Authors conclude no causal effects.
Entorf and Kramarz (1997)	OLS earnings equations with firm and individual characteristics, controls for individual dummies in some specifications	French TOTTO (1987 survey of new technology use) matched to individual and firm panel (3,694 individuals in the panel, with 8,192 observations). 1985-87	Time at which an individual started to use a new technology (e.g. computer); experience with computers	Education, tenure, firm skill shares, assets, exports, profits, size, occupation, industry, time dummies, part-time, experience	No linear effect of technology after controlling for fixed effects; evidence of an interaction of NT use with experience (quadratic)
Hildreth (1998)	OLS earnings functions with detailed plant and individual controls; imports and technology as IVs for profits	Matched establishment-worker data survey; 1994 UK manufacturing; 685 plants	Introduction of process and product innovation	Age, gender, union, education, occupation, workplace conditions, profits	Process innovations have bigger effects on estimates of rent-sharing
Krueger (1993)	OLS earnings functions	1984 and 1989 US	Computer use (broken	Education, experience,	19-21% premium for

	with dummy for computer use interaction with education	October CPS (c. 13,000 individuals); High School & Beyond Survey (4,684)	down by purpose – e.g. programming, e-mail)	race, MSA, part-time, veteran, gender, marital status, union, occupation (8), region (3)	computer use; higher for educated; effect higher in 1989 than 1984
Loh (1992)	OLS wage regressions, and training probit	US Current Population Survey (1983), matched to some industry level data	Industry-level R&D and equipment age	Age, gender, race, union membership, employment, education, experience	Positive effect of innovation on hourly wage, particularly in union sample. Training more likely for workers in innovative industries
Reilly (1995)	OLS wage regressions investigating employer size-wage effect	607 Canadian employees in 60 firms, 1979	Access to a computer	Education, experience and tenure, supervisors per employee, capital stock per employee, age of capital stock	Positive effect of technology and wages accounts for the employer size-wage effect
Troske (1999)	OLS earnings equations with plant and worker characteristics	118,320 individuals from the WECD (LRD and 1990 Census) and the 1988 SMT	Use of manufacturing technologies and computer investment in plant (not individual specific)	Size of plants, capital in plant, individual characteristics	No effects of plant computer presence conditional on plant characteristics

Table 4.3: The effect of technology on employment

A. Industry level					
Study	Method	Data	Proxy for technology	Controls	Result
Berndt, Morrison and Rosenblum (1992)	OLS regression of L/Q on K/Y and two other types of capital intensity (equipment and high tech)	See Table 4.1.A.	See Table 4.1.A.	Time	Positive effect of high tech capital on employment intensity
Nickell and Kong (1987)	4 equation system (pricing, production, wages, demand)	55 UK manufacturing industries (3-digit), 1974-85 panel	Residual based approach	Various - capital, average wages, etc	In 7 out of 9 sectors a positive effect of labour augmenting technical change
B. Enterprise level					
Study	Method	Data	Proxy for technology	Controls	Result
Blanchflower, Millward and Oswald (1991)	Employment growth regression (managers asked about employment in previous years)	UK 1984 WIRS (cross section) 948 establishments	Any introduction of new technology involving micro-electronics in last 3 years	Age, unions, demand, ownership	Positive and significant in Britain
Blechinger, Kleinknecht, Licht and Pfeiffer (1998)	I OLS static conditional labour demand equations separately for each country	I Manufacturing firms in Germany (1,821), Denmark (528), France (3,600), Norway (743), Spain (1,998), Luxembourg (241), Belgium (557), Italy (16, 374) in 1992	I Community Innovation Survey (CIS) – subjective question; whether firm performs any R&D; whether R&D directed at product or process	I Sales, sales squared, labour costs (industry level), qualitative indicators of barriers to innovation, exports, subsidiary status	I Innovation indicator insignificant in every country except Italy (more small firms); R&D has a positive correlation (probably due to fixed effect)
Blechinger et al (1998) - cont.	II Employment growth 1988-92 on 1988 characteristics; separate estimation for mnfg and services; attempt to control for survival bias using Heckman method	II 772 mnfg and 836 service firms in Netherlands	II. Product and process R&D personnel %; indicators for office and production automation	II Dummies for size class	II R&D has positive effect in both sectors (process stronger than product); office automation positive effect in services; production automation positive effect in mnfg
Blanchflower and Burgess (1999)	Employment growth regression	1990 UK WIRS (831 plants), 1992 Australian AWIRS (888 plants)	Any introduction of new technology involving micro-electronics in last 3 years	Employment 4 years earlier; unions, financial performance, ownership	Positive and significant in Britain; positive and weakly significant in Australia

Brouwer, Kleinknecht and Reijnen (1993)	1983-88 employment growth regressions, Heckman two step selectivity correction (no real identifying instruments)	1983 and 1988 859 Dutch manufacturing firms (survey)	R&D intensity, type of R&D	Firm size, industry sales growth, single plant, lagged firm sales growth, industry dummy	No effect of R&D intensity level, growth of R&D intensity has significant negative effect; mitigated by product R&D and R&D towards IT
Doms, Dunne and Roberts (1994)	Employment growth (and survival)	US plants from LRD and Survey of Manufacturing, 1987-91	Dummy variables for numbers of advanced manufacturing technologies in the workplace	Age, capital, size, productivity	Positive effects
Entorf, Gollac and Kramarz (1999)	Multinomial logit of individual employment paths, with individual fixed effects, controlling for economic conditions in some specifications	EE, the French household-based labour force survey; TOTTO, the 1993 technology supplement to the labour force survey; EET, the quarterly follow-up to the EE; and DMMO, an establishment based survey of labour turnover	Computer use, computer experience, use of other types of new technology (e.g. robot, video, fax)	I Gender, education, region, part-time indicator, occupation, size and status of employer, experience, firm age; II establishment turnover rates, experience, firm age, part-time indicator, retirement rate	Computer use protects workers from unemployment in the very short run, but not in the long run
Entorf and Pohlmeir (1991)	3 system equation (exports, innovation, employment); GLS	2,276 German firms in 1984 (IFO)	Responses to a survey of innovation	Export/sales, labour costs, concentration	Product innovations have positive effect; process innovations no effect
Greenan and Guellec (1997)	3 equation sysem with value added, labour and capital as endogenous, growth regressions	Balanced panel of up to 5919 firms 1985-91 in France	Indicator of intensity of process and product innovations in 1991	Labour costs, capital costs, size, industry	Innovating firms create more jobs; product innovs create more jobs at sector level; process innovs create more jobs at firm level (zero at sector level)
Klette and Førre (1998)	OLS estimation of job creation rates, weighted by employment shares	Over 4,000 Norwegian manufacturing firms, 1982-92	R&D intensity	Industry and time dummies, size, foreign competition	Slower growth of Norwegian high R&D firms compared to low R&D firms
Konig, Buscher and Licht (1995)	OLS and probit estimation of factor demand models	c. 3000 German firms from Mannheim Innovation Panel and Mannheim Enterprise	Broad range of subjective indicators	Cost of capital, wages, demand expectations	Positive effect for product innovation; none for process innovations; expected

		Panel in 1993			demand most important
Leo and Steiner (1994)	OLS and multinomial logit models for changes in employment; lags of innovation	400 Austrian firms from WIFO (Institute of Economic Research), 1990-92	Technology and Innovation survey		Positive effect from lagged product innovations; no effect from process innovs
Regev (1995)	Employment growth regressions	3,260 Israeli firm observations, 1982, 1985, 1988, 1992	Technology index based on R&D, skilled labour and capital vintage	Industry and time dummies, size of firm, export and imports, concentration	Positive effect
Ross and Zimmerman (1993)	Probits of planned stock of labour	5,011 German firms (manufacturing) from Munich IFO Institute in 1980	Subjective survey	Demand, labour costs	Negative effect of process innovations
Smolny (1998)	OLS estimate of employment changes	1980-1992 unbalanced panel of 15,992 obs (c.2405 firms) in West German mnfg (IFO)	Subjective survey (IFO), Lagged variables	Capacity utilisation, investment/sales ratio, size dummies, time dummies	Positive and signif impact of firm product innovs; industry product innovs have a significant negative effect on employment growth (rivalry); no significant effect of firm process innovs but signif positive effect of industry process innovs; higher volatility of employment for product innovs
Van Reenen (1997)	Dynamic employment growth model; OLS and GMM;	Unbalanced panel of 598 quoted UK manufacturing firms 1976-82	Major innovations (SPRU) counted at firm and industry level (expert survey); firm level patents (taken in U.S.)	2 lags of employment, wages, capital, industry innovation, time dummies, long lags of innovation and patents	Innovations (esp. product) have large effects on employment; patents effects not robust to fixed effects
Zimmerman (1991)	Probit model for planned change in labour stock	3,374 German firms in 16 industries from IFO	Subjective survey	Demand, labour costs	Negative effect of process innovations