The United Nations University
WIDER
World Institute for Development Economics Research

Working Papers No. 152
October 1998

Computers and Labour Markets: International Evidence

Francis Kramarz

Computers and Labour Markets: International Evidence

Francis Kramarz

CREST-INSEE
Malakoff Cedex, France

and

CEPR
London, United Kingdom

October 1998

This study has been prepared within the UNU/WIDER project on Information Technology and Economic Development, which is directed by Professor Matti Pohjola.

UNU/WIDER gratefully acknowledges the financial contribution to the project by SITRA (Finnish National Fund for Research and Development).

UNU World Institute for Development Economics Research (UNU/WIDER)
A research and training centre of the United Nations University

The Board of UNU/WIDER

Nora Lustig
Harris Mutio Mule
Sylvia Ostry
Jukka Pekkarinen, Vice Chairperson
Maria de Lourdes Pintasilgo
George Vassiliou, Chairperson
Ruben Yevstigneyev
Masaru Yoshitomi

Ex Officio

Hans J. A. van Ginkel, Rector of UNU
Giovanni Andrea Cornia, Director of UNU/WIDER

UNU World Institute for Development Economics Research (UNU/WIDER) was established by the United Nations University as its first research and training centre and started work in Helsinki, Finland in 1985. The purpose of the Institute is to undertake applied research and policy analysis on structural changes affecting the developing and transitional economies, to provide a forum for the advocacy of policies leading to robust, equitable and environmentally sustainable growth, and to promote capacity strengthening and training in the field of economic and social policy making. Its work is carried out by staff researchers and visiting scholars in Helsinki and through networks of collaborating scholars and institutions around the world.

UNU World Institute for Development Economics Research (UNU/WIDER)
Katajanokanlaituri 6 B
00160 Helsinki, Finland

Copyright © UNU/WIDER and SITRA 1998

Camera-ready typescript prepared by Liisa Roponen at UNU/WIDER
Printed at Pikapaino Paatelainen Oy, Helsinki

The views expressed in this publication are those of the author(s). Publication does not imply endorsement by the Institute or the United Nations University of any of the views expressed.

ISSN 0782-8233

CONTENTS

ABSTRACT iv

1. INTRODUCTION 1

2. COMPUTERS AND INDIVIDUAL WAGES IN THE US AND WESTERN EUROPE 1

   2.1 Cross-section evidence 1
   2.2 Panel datasets evidence 7
   2.3 Evidence from industry, education, or occupation cells 11

3. COMPUTERS AND EMPLOYMENT IN THE US AND WESTERN EUROPE 15

   3.1 Evidence from individual-level data 15
   3.2 Evidence from industry, education, or occupation cells 18

4. COMPUTERS AND THE WORKPLACE ORGANIZATION 21

5. CONCLUSION: SHOULD WE BELIEVE IN SKILL-BIASED TECHNICAL CHANGE? 23

   5.1 A discussion of the above evidence 23
   5.2 Implications for developing countries 24

DATA APPENDIX 25

REFERENCES 28

ABSTRACT

The rapid diffusion of computers has widely changed the consequences of computer use on the labour market. While at the beginning of the eighties knowledge of computers was an obvious advantage in a career, this same knowledge is now so commonplace that the inability to use these tools is widely seen in many industries as a professional handicap. In relation to such drastic transformations, changes in the North American wage structure during the eighties in favour of the better educated have been interpreted by many analysts as evidence of skill-biased technical change. Evidence outside the US, and in particular in Europe, seems to support the idea that similar transformations affected most other labour markets.

In this study, we review the empirical evidence on the relation between computer use and labour market outcomes. More precisely, we examine the relation between the broadening use of computers on one side, and wages, skill-composition of the workforce and unemployment on the other. All evidence presented seems to point to the following conclusion: Something is going on, but there is no reason to call it skill-biased technical change in its simplest acceptance. Why should we otherwise observe such different trends in the United States and in Europe? The computer is used everywhere in the developed countries, and the diffusion rates are roughly equal. Furthermore, the machines and softwares used are increasingly similar and delivered simultaneously. Hence, if trends on the various labour markets are caused mostly by technical change, these trends should also be very similar. This does not seem to be what is happening in the Western world. Institutions with both classical supply and demand factors should be able to explain a large fraction of the observed facts. Moreover, it also seems apparent that what matters in a period of rapid diffusion of computers is interpersonal skills; such skills are complements to computer use. Indeed, more research should be devoted to the study of the internal organization of the firm in a highly computerized environment.

1. INTRODUCTION

The rapid diffusion of computers has widely changed the consequences of computer use on the labour market. While at the beginning of the eighties, knowledge of computers was an obvious advantage in a career, this same knowledge is now so commonplace that the inability to use such tools is widely seen as a professional handicap in many industries.

In relation to such drastic transformations, changes in North American wage structure in favour of the better educated during the eighties have been interpreted by many analysts as evidence of skill-biased technical change (see Katz and Murphy 1992; Bound and Johnson 1992; Murphy, Riddell, and Romer 1998, among many others). Evidence outside the US, in particular in Europe, seems to support the idea that similar transformations affected most other labour markets (see Machin and Van Reenen 1998; see also Chennells and Van Reenen 1998 for a recent survey on the impact of technical change—based on innovations, R&D, as well as computers—on labour market outcomes and Shaw 1998 for an analysis centred on the steel industry).

In this article, we will review the empirical evidence on the relation between computer use and labour market outcomes. More precisely, we will examine the relation between the broadening of computer use on one side and wages, skill-composition of the workforce, and unemployment on the other.

2. COMPUTERS AND INDIVIDUAL WAGES IN THE US AND WESTERN EUROPE

2.1 Cross-section evidence

Krueger (1993) is the seminal paper on the impact of computer use on wages. It may be one of the most cited paper written in the recent years. The question posed is very simple. Is it possible to find a premium for computer use? In case of a positive answer, is the premium a sign of an increase in the individual's productivity or mere evidence of unobserved person heterogeneity. Most of Krueger's analysis is based on the 1984 and 1989 Current Population Survey (CPS). Both surveys contain a supplement on computer use. The equation estimated is extremely simple. If $Comp_i = 1$

denotes that worker i uses a computer at the date of the survey, the first wage equation to consider is:

$$(1) \qquad w_i = \alpha \, Comp_i + X_i \beta + \varepsilon_i,$$

where w_i is the wage of worker i, where X_i are observable characteristics of worker i, and where ε_i is the error term. In the empirical work, Krueger estimates equation (1) with a variety of controls. He shows that workers who use computers receive a premium of approximately 20 per cent. This premium seems to increase over time, from 1984 to 1989 from 18.5 per cent to 20.6 per cent (Table II of Krueger 1993) while the proportion of computer users in the population is also increasing (from 24.6 per cent to 37.4 per cent, Table I of Krueger 1993). The main question that is now posed, once evidence for a computer premium is demonstrated, is the origin of this premium. We may summarize this question as follows: Is the computer premium real, in that it is induced by a productivity increase of the worker who uses a computer, or does it reflect some sort of unobserved worker or employer heterogeneity, positively correlated to both computer use and wages? Krueger devotes the rest of his analysis to this precise question.

First, Krueger introduces employer information to control for possible correlation between computer use and the generosity of compensation such as two-digit industry indicators or the union status of the workers (he cannot control for size, but cites Reilly (1995) who can do it but finds little change on the computer premium for a very small sample of Canadian workers). In the non-union sector, he finds a premium of 20.4 per cent while in the union sector, it is just 7.8 per cent. Krueger concludes as follows: 'if one believes that the premium for work-related computer use is a result of employees capturing firms' capital rents rather than a return to skill, it is difficult to explain why the premium is so much larger in the nonunion sector than in the union sector'. Interestingly, he examines the various returns for various specific computer tasks. Krueger shows (see his Table III) that electronic mail is the most rewarded task (coefficient of 0.149 to add to the 0.145 coefficient on use computer at work) while the -0.109 coefficient on computer games seems to suggest that computer use for non-productive tasks does not increase earnings (add 0.145 to -0.109). Krueger just notes about the e-mail coefficient that it reflects the high-ranking of e-mail users. In some sense, he argues for some sort of unobserved heterogeneity.

To tackle this issue more directly, Krueger also uses information on computer use at home as opposed to computer use at work. If the computer premium reflects productivity differences, Krueger argues that one should see a zero coefficient on the indicator for using a computer at home in an extended wage equation. He finds that computer use at home is associated with a positive, 7 per cent, premium. He concludes from these evidence that 'computer use at work influences earnings and not characteristics that are associated with computer use'.

His final piece of evidence, of interest for us in this survey, is the relation between computer use and returns to education. To do this, he re-estimates the same basic cross-section equation (1) with a small modification:

$$w_i = \alpha \, Comp_i + \gamma \, Comp_i \times edu_i + X_i \beta + \varepsilon_i ,$$

where edu_i denotes the number of years of education of worker i. Results are striking. The direct computer premium, α, vanishes while all of the effect of computers goes through education, γ, which is equal to 0.013 in 1989. This allows Krueger to conclude that the increase in computer use can account for roughly 41 per cent of the increase in the return to education in the American private sector.

Troske (1997), in a study of the employer-size wage premium using the Worker-Establishment Characteristics Database (WECD) (see the data appendix), tries to see whether this premium comes from failing to include an adequate description of the capital in the worker's plant. To do this, Troske uses as a measure of what he calls the 'skill capital', the log of total new investment in computers in the plant in 1987 divided by total employment in the plant in the same year. This information comes from the Census of Manufacturers. Other researchers mentioned in our survey have used these data, which measure flows and not stocks of the relevant variable. The WECD is the result of a match between the long form of the 1990 decennial census (i.e. individual-level information) with the Longitudinal Research Database (LRD) from the US census which contains longitudinal information on manufacturing plants. The models estimated by Troske are as (1) in which variables on the plant are added to the person characteristics. Each regression includes 118,320 observations. Table 6 of Troske (1997) presents the results of interest for us. First, when no information on the establishment other than 2-digit industries, region, location of the plant, and the computer investment variable, Troske shows that, in conformity with Krueger's results, workers employed in plants with larger computer investments receive higher wages, even after controlling for personal characteristics of the individuals. However, when the author includes the log of the establishment employment, the log of the firm (to which the establishment belongs) employment, and the labour-capital ratio, the effect on the computer investment variable disappears. In addition to this evidence, Troske matches the WECD with the 1988 Survey of Manufacturing Technologies (SMT), resulting in a smaller subsample but with direct information on the presence of a computer in the worker's plant. Results are presented in his appendix, see his Table 3. They show that, once more consistently with Krueger's results, workers working in a computerized plant receive a 11 per cent premium. Once more, when Troske introduces the size and the capital-labour ratio, all effects on the computer variable disappear. Notice however, that the information on computers is far from perfect since Troske mixes precise individual characteristics and imprecise ones on computer existence in the plant.

The idea that, indeed, most of recent changes in the wage structure have been caused by the diffusion of new technologies, as exemplified by computers, has been extremely successful. Of course, to conclude that there is skill-biased technical change, one must prove that the results observed for the US are also valid in other countries. The first evidence comes from Finland, France, Germany, and the UK.

But, first, we need to show that the spread of computer use is roughly equal across various countries and that the users have roughly identical characteristics. To compare the US and European countries, it is possible to use a paper written by Card, Kramarz, and Lemieux (1996). These authors show that computer use at the end of the eighties is very similar in Canada, France, and the United States: slightly below 35 per cent in the first two countries and slightly above 35 per cent in the US.[1] They also show that in all three countries, women and educated workers use computers more than other types of workers. Indeed, all available evidence demonstrates that computer spread is very similar across various developed countries (see also OECD 1998). Furthermore, and this will become more obvious after the next paragraphs, the impact of computers on earnings is also very similar across various developed countries.

DiNardo and Pischke (1997) using a German dataset, the SOEP, have further examined the question of unobserved heterogeneity in returns to

[1] Results are based on Krueger (1993) for the US, Lowe (1991) for Canada, and the 1991 LFS for France.

computer use. The subtitle of their paper is the best summary of their finding: 'Have Pencils Changed the Wage Structure Too?' They reproduce Krueger's regression for a comparable date and first show that returns to computer use are extremely close in Germany to those observed in the US. They go a step further and show that workers who use pencils on their jobs are also better compensated (the premium being almost identical to the one observed for computers). They conclude that the computer premium reflects unobserved personal characteristics, positively correlated to wage and computer use. Indeed, a 15 per cent to 20 per cent computer use premium is a general finding of most studies. Bell (1998), using a dataset of approximately 1,000 English persons all born in March 1958, shows that computer users are better compensated than non-users. Chennells and Van Reenen (1998) give other examples of studies, using firm or individual data, for the UK that confirm such cross-sectional findings.

Entorf and Kramarz (1997 and 1998) and Entorf, Gollac, and Kramarz (forthcoming) demonstrate that an identical result also holds in France. Since we refer to these studies more extensively in the next sections, we provide the reader with a detailed data description in the Appendix. To summarize their basic features, the data used by Entorf and Kramarz come from four different INSEE sources. The basic sources are the French Labour Force Surveys (LFS), 1985-87, a three-year rotating panel, and the *Enquête sur la Technique et l'Organisation du Travail auprès des Travailleurs Occupés* (TOTTO) of 1987, an appendix to the labour force survey that asked questions about the diffusion of new technologies and the organization of the work place. Besides the usual questions from labour force surveys (salary, tenure, age, education, etc.), the appendix contains information on the use (e.g. intensity, experience) of microcomputers, terminals, text processing, robots and other well specified groups of 'new technology' labour. The use of computers is described in more detail than in other surveys (Krueger 1993 for instance). The questionnaire provides explicit categories for using microcomputers for text processing only, data entry and use of listings. 'Terminal' even covers a distinction between 'reception only', 'emission only' and both reception and emission while information on production techniques are also present.

In the first version of the TOTTO survey, only the 1987 employing firm is known (using the standardized Siren enterprise identification number). This feature of the French INSEE classification system enables the authors to employ information from corresponding firm-level surveys (BIC, which collects annual information on balance sheets and employment and ESE, which collects information on the employment structure).

In the cross-section, the approach is identical to Krueger's (1993). Entorf and Kramarz regressed the log of monthly wage on a vector of characteristics of the individual X_i and a vector of indicator variables for workers using one (or more) of the various new technology (NT) groups (equation (1)). In some regressions, these variables were supplemented with firm-level characteristics $Z_{j(i)}$ (where $j(i)$ denotes the firm at which i is employed), some of which are available from the complement to the labour force survey (working time schedules, sector, size) and the others from the firm-level panel dataset (size, assets, profits, skill structure, export ratio). In all regressions, they control for the usual observable variables. Their results show that in 1987 a worker received a 16 per cent bonus for using modern computer-related NT. This premium can be decomposed into two parts: for a worker with no NT-experience, a NT worker receives a premium of approximately 6 per cent. Returns from experience with NT add 10 per cent to the above premium (when estimated at the average level of experience in the population of modern computer-related NT users). When firm-level variables are introduced, some of the above results seem to be attenuated: the coefficient of the modern computer-related NT dummy is smaller (5 per cent) and the standard error is larger. However, the role of experience with modern computer-related NT is increased. The firm-level variables that are used, even if they do not seem to be correlated with the individual NT variables, are important and increase significantly the explanatory power of the regression. In that respect, these last results seem to contradict those of Troske (1997), but remember that Troske does not know if a given worker in a plant actually uses a computer but only that computers are present in the plant. Finally, if firm fixed-effects are introduced, results are unchanged.

Most of the results that have been described for the 1985-87 period also hold between 1991 and 1993. The datasets are roughly identical. A new feature of the LFS is the inclusion of the employing firm identifier in every year while only the 1987 employing firm was known previously (see above). In addition, the authors use a newly available dataset, the *Déclarations de Mouvements de Main d'Oeuvre* (DMMO), an establishment-based survey on hiring and separations. Entorf, Gollac, and Kramarz are therefore able to follow the workers across firms in the three years of the panel.

Entorf, Gollac, and Kramarz estimate wage equations like (1) with NT indicator variables in the Krueger fashion as well as with firm fixed effects. Returns to computer use in 1993 are not different from those observed in 1987. The introduction of firm fixed-effects has no impact on the estimated coefficients.

Asplund (1997) presents very interesting evidence for Finland. She uses the bi-annual labour force survey for the years 1987, 1989, 1997, and 1993. The first striking feature is that Finland appears to be the country in which computer use is the most widespread. The proportion of users increases from 33.0 per cent in 1987 to 56.4 per cent in 1993 (see her Table 1). Then, she estimates the same model as all other authors have estimated in the cross-section dimension. Computer users receive a 7 per cent premium when using a computer in all years between 1987 and 1991. In that, there is no difference with other countries (even though the premium appears to be smaller). But, in 1993, the premium disappears almost completely and does not seem to be significantly different from zero in average (see her Tables 2 and 3). Notice however that women seem still able to capture some returns to computer use in 1993 (see her Table 4). If we believe that the premium reflects unobserved heterogeneity, the large increase of computer use in Finland seems to have been associated with the attenuation of the selection process of the best workers: almost everyone has to use such machines.

2.2 Panel datasets evidence

Evidence on computers based on panel datasets comes only from two countries: France and the United Kingdom. In France, the studies of Entorf and Kramarz (1997 and 1998), and Entorf, Gollac, and Kramarz (forthcoming) give exactly the same result. These authors estimate the following equation with person fixed effects:

$$(2) \qquad w_{it} = \alpha\, Comp_{it} + X_{it}\beta + \sum_{k} 1_i(k)\, e_k + \varepsilon_{it},$$

where $1_i(.)$ is an indicator for individual *i,* and where computer use is time-varying. To incorporate the potentially increasing productivity of computer users, X_{it} may include the number of years of experience with computers of individual *i* at date *t*.

To assess firm-specific compensation policies, Entorf, Gollac, and Kramarz (forthcoming) add to the previous equation (2) firm fixed-effects. Hence, the final estimated equation is:

$$(3) \qquad w_{it} = \alpha \, Comp_{it} + X_{it}\beta + \sum_{k} 1_i(k)e_k + \sum_{l} 1_{J(i,t)}(l)\, f_l + \varepsilon_{it}$$

in which $1_{J(i,t)}(.)$ is an indicator for firm $J(i,t) = j$ at which individual i is employed at date t.

The results obtained in all three papers are fully consistent with each other. Both in 1987 and in 1993, when estimated in this longitudinal dimension, all the effects of computer use on wages that are observed in the cross-section almost completely disappear. The coefficients on the computer use indicator variable are never significantly different from zero.[2] However, even though NT use per se does not yield an immediate wage gain, coefficients of the experience with modern computer-related NT variables are significantly different from zero. In Entorf and Kramarz (1998), another version of the same equation in which a dummy for each year of experience (1, 2, …, 9 and more) is included is estimated and results are quite similar: returns increase until workers have 5 to 6 years of experience and then slightly decrease. The introduction of the firm-level variables do not change these results. In addition, the firm-level variables that measure the firm-specific policy have little impact on the individual wage once individual fixed effects are introduced. Coefficients are either not significantly different from zero or small (assets). To test for other explanations of the results (in particular, to control for firm-level idiosyncratic shocks), Entorf, Gollac, and Kramarz (forthcoming) use the matched worker–establishment information on hiring, quits, and terminations coming from the DMMO. By introducing establishment-level measures of entries and separations, they can check that the absence of effect in the longitudinal dimension does not come from some unobserved firm-specific component, related to year to year variation in profit that would go against wage increases that should normally accrue to the computer users. All their results are basically identical to those described above. In addition, these authors test for measurement error in the retrospective information on computer use. They also give evidence that demonstrates that measurement error is not a serious problem in their dataset.

Based on an English dataset (described above), Bell (1998) can examine related issues. In fact, since he has information on computer use in 1991 as

[2] This result holds for all new technologies (NT) that are analysed by these authors.

well as wage data in 1991 and in 1981, he is able to examine the wage growth of computer users versus non-users. He finds a small positive and significant effect on the computer use dummy. This analysis has, unfortunately, some drawbacks. First, the dataset only surveys workers born in March 1958, a generation who may not be exactly representative of the whole British labour force. Then, the hypothesis that no one used computers at the earlier date, 1981, is certainly strong. Furthermore, the period between the two dates, ten years, is quite long and many things could happen in between without forcing us to attribute some wage growth to computer use.

Since there exists no dataset with the kind of information that was used in France or the UK, American researchers have tried other approaches and datasets. First, Bartel and Sicherman (1996) mix individual information and industry-level information. They start with the American National Longitudinal Survey of Youth (NLSY) (main file and work history file of the 1979-93 NLSY aged 14-21 in 1979). Since the dataset does not contain information on the exact technical changes faced by an individual, the authors link the NLSY with other datasets using the industry classification. Of interest to our discussion here is the investment in computers which comes from the 1982 and 1987 census of manufacturers. This investment is measured as the ratio of investment in computers to total investments. Bartel and Sicherman use approximately 50 industries (2-digit classification). Then, they estimate a wage equation with a person and an industry effect. They show that wage changes in industries with high computer investments are larger than in those industries with low computer investments. However, they also show that wage changes in industries that increased their computer investments between 1982 and 1987 are not significantly larger than wage changes in other industries. It is indeed this last equation which is more consistent with the type of thought experiment that we have in mind, i.e. what is the impact of an increase in computer use (for individuals, from non-user to user).

Doms, Dunne, Troske (1997) also mix information from various origins. Their basic dataset is a match of individual-level information from the long form of the 1990 decennial census with establishment-level longitudinal information (LRD). This match is called the WECD.[3] To have information on technology use, the authors match the WECD with the Survey of Manufacturing Technologies (SMT) from 1988 and 1993. We describe in

[3] Also used by Troske (1997), analysed above.

more detail the procedure of the match in the data appendix. The 1988 SMT contains plant-level information on NT use in American manufacturing plants. The techniques surveyed are production technologies such as robots, computer-aided design (CAD), lasers, networks, automatic systems, or computers used on the factory floor. To assess the technical development of the plant, the authors use the count of different techniques used at the plant. They build 5 categories of plants based on the number of technologies used. The SMT is matched to the WECD. This allows Doms, Dunne, and Troske to build the average earnings for production workers, for technical, clerical and sales workers, and for managers and professional workers for the 358 establishments present in all three datasets. At the same time, they use the observed characteristics of the same workers to compute the per cent of workers in 4 education categories, the per cent of the workforce in three age categories, the per cent of married workers, of male workers, and finally, of white workers. Finally, they measure the plant-level employment and its capital-labour ratio. Then, they include all these variables to perform establishment level regressions to measure the wage premium to being employed in a technologically advanced plant. Indeed, consistently with all other results examined until now, they show that workers employed in those plants which use many modern techniques, in particular computers, are better compensated (here the premium is roughly equal to 10 per cent for production workers and technical or clerical workers, and zero for managers, see their Table III).

These results show that, as in Krueger (1993), technology use is associated with a premium even after inclusion of workers characteristics. Then, using the LRD and the 1993 SMT, a longitudinal analysis can be performed to check whether this premium disappears or remains in this longitudinal dimension. First, Doms, Dunne and Troske examine in the same spirit as Bell (1998) the long changes in earnings between 1977 and 1992 in relation to the technological status of the plant in 1993 (using the 1993 SMT). Their results show that the most technology-advanced plants in 1993 paid their workers higher wages in 1977 (see their Table IV). The 1993 SMT contains information on the timing of technology adoption, i.e. the number of technologies adopted between 1987 and 1992 while the census of manufactures in 1987 and 1992 contain earnings information for production and non-production workers. This allows Doms, Dunne, and Troske to repeat the previous analysis using these wages, first by using only information from the 1993 SMT, then by measuring the difference in the number of technologies declared in 1988 and 1993. All these regressions give identical results. All the effects of technology disappear in this longitudinal dimension. Firms that pay high wages and use many modern techniques already paid well before adopting these techniques. In a last attempt, Doms, Dunne, and Troske match their sample with data from the 1992 Annual Survey of Manufactures (ASM) from which they use a measure of computer investment. When examining the changes in earnings of either production or non-production workers in relation to computer investment, they show the absence of such a relation. Those plants which have invested highly in computer equipment did not increase their wages between 1977 and 1992.

2.3 Evidence from industry, education, or occupation cells

In this subsection, we review all of the evidence on the impact of computer use on wages, or relative wages based on longitudinal datasets of industries, occupations, or education cells constructed from various individual, establishment or firm-level datasets. This analysis will cover various countries. For the moment, we will only present rough evidence, delaying the much debated question of skill-biased technical change for a later section.

Most papers typically derive their estimated equations from a simple model with a CES production function with different factors of production. For instance, in Mishel and Bernstein (1996) and Autor, Katz, and Krueger (1997), the units of interest are industries (34 for the former and 140 in the latter) and each sector has at least two types of workers, high school and college graduates while Card, Kramarz, and Lemieux (1997) use age-education cells to examine changes in inequality. The typical equation has a measure of within-industry changes (for the first two studies) in relative demand for college-educated workers versus high school-educated workers as the dependent variable and some measure of the technical shocks that affected the same industry as the explanatory variables. In this survey, we will focus on those results in which the explanatory variables include computer use in the industry (either in level or in variation). Furthermore, in this subsection, we concentrate on the changes in the relative wages.

Mishel and Bernstein (1996) examine the 1973 to 1994 period, decomposed into three subperiods: 1973-79, 1979-89, 1989-94. Their data come from the CPS (outgoing rotation groups) together with the 1990 Public Use Microdata Sample (PUMS) for the dependent variables while the explanatory variables comprise the Bureau of Economic Analysis (BEA) gross computer stock per full-time equivalent from the National Income and Product Account (NIPA) series (called computer investment per FTE). The wage inequality measure for each industry is computed as follows: the authors divide each industry wage distribution into various fractiles (0-20, 21-50, 51-75, 76-90, 91–100) for each sex. Then, they measure their wage quantities relative to the 1979 wage distribution. All the equations are estimated in first difference to eliminate all industry fixed effects. The resulting estimates should help us to assess whether technology changes are associated with an increase use of high wage workers. Their Tables 11 and 13 contain the results for men. The authors show that technological change was less biased in the eighties than in the seventies for the bottom half of the wage distribution. Indeed, 'There is definitely no support for an accelerated technology effect working against the bottom half in the eighties.' In addition, 'relative to the seventies, technological change in the eighties was less favourable to the highest paid 25 per cent of men.' Finally, for men again, the estimates in the nineties appear to be even less consistent with the skill-biased technical change ideas, since for every wage group, the estimated coefficients are small. The same equations are estimated for women (see their Table 12). The conclusion of the authors is quite similar to the one obtained for men since they claim that there is once more 'no support for an accelerated technology shock hurting the bottom half or three-fourths and helping the top half.'

Autor, Katz, and Krueger go a step further by examining a longer time period (1940 to 1995) and a larger number of industries (140). Their basic framework includes an aggregate CES production function, y, with two factors, college equivalents, c, and high school equivalents, h:

$$y_t = \left[(s_t x_{ct})^{\frac{\sigma - 1}{\sigma}} + (x_{ht})^{\frac{\sigma - 1}{\sigma}} \right]^{\frac{\sigma}{\sigma - 1}}$$

where c stands for college and h for high school while w stands for wage and x for quantities, where s is a measure of the relative efficiency of college-educated workers with respect to high school-educated workers, t stands for time, and, finally, σ is the elasticity of substitution between college and high school equivalents. Maximization of this aggregate production function leads them to the following index for the log relative demand shift, D_t, equation:

$$(4) \qquad D_t = \log\left(\frac{w_{ct}x_{ct}}{w_{ht}x_{ht}}\right) + (\sigma - 1)\log\left(\frac{w_{ct}}{w_{ht}}\right).$$

This last parameter is crucial since if σ has values between 0.5 and 1, then 'one can reach the conclusion that supply growth differences entirely explain differences in wage behavior in the seventies versus the eighties without resort to a new era of rapid skill-biased technical change' as stated by the authors whose preferred estimate of this elasticity is 1.4 (Katz and Murphy 1992).

Their measure of computer use is similar to Krueger's (1984 and 1988 CPS) to which they add the 1993 CPS. This allows them to evaluate the proportion of computer users in each industry. These numbers are transformed into annual changes in the fraction of workers in each industry who use a computer. Consistently with equation (4), they examine the annualized change in the share of payroll due to college-educated workers in each industry from the sixties to the nineties and explain it with the 1984-93 annualized change in computer use. Their Table 7 shows that the 1960-70 inter-industry changes in the wage bill share of college-educated workers are only weakly related to future changes in computer use. The relation is stronger in the later periods. Autor, Katz, and Krueger note that the coefficients in the seventies and in the eighties are of the same magnitude. Furthermore, the results appear to account for a substantial increase in the share of the payroll accruing to college-educated workers (roughly one-half between 1980 and 1990, a similar number for the seventies, the same number between the sixties and the eighties).

To check the stability of their results on a longer period (from 1960 to 1990), Autor, Katz, and Krueger use measures of computer investment from the NIPA series also used by Mishel and Berstein (see above). The number of sectors is reduced to 41 since these data only include private sector capital (non-agricultural industries excluding service sectors with substantial government employment). They show that there exists a strong positive relationship between the computer investment measure (per unit of employment) at the start of each decade and the growth of the college-educated workers payroll share over the following ten years. They also mention that in explaining the college wage bill share, what matters is the initial stock of computer capital rather than changes during the period in computer capital. Replacing computer investment per full time employee by the average computer use in the same industry from the 1984 CPS gives close results while having variables both in the same regression drives the computer investment coefficient to non-significance.

The authors also examine the skill-upgrading issue by explaining the share of non-production workers in the wage bill of each industry. They use data on 450 industries from the NBER productivity database for the period 1959 to 1989. Apart from computer investment from the Census of Manufactures and the share in the payroll of non-production workers, they use data on changes in capital intensity, real shipments growth, and total factor productivity growth from the NBER productivity sample, import and export penetration from Feenstra (1996) and the outsourcing measure from Feenstra and Hanson (1996). Their estimates (Table 10) show that the changes in computer investment can explain roughly a third of the acceleration in skill upgrading in manufacturing from the seventies to the eighties. By contrast, changes in imports, exports, or in outsourcing explain very little of the growth of the wage bill share for non-production workers. These findings are consistent with the earlier findings of Berman, Bound, and Griliches (1994), who used the same type of approach and data but on a smaller period and at a less disaggregated level, and who italicized the following finding: 'Investments in computers alone would seem to account for between one-quarter and one-half of the within-industry move away from production labour that occurred over the eighties.'

The conclusion that the reader can derive from Autor, Katz, and Krueger is clear: 'Whatever is driving increases in the rate of growth of demand for skilled labour over the past twenty-five years is concentrated in the most computer-intensive sectors of the US economy.'

Card, Kramarz, and Lemieux (1997) do not focus on skill-biased technical change *per se* as the previous authors did. However, they examine the question of the evolution of relative wages in the eighties. More precisely, they examine the claim that it is because wages are inflexible in Europe (here, France) in spite of negative shocks against low-skill workers that these workers lost their jobs. And, since computer use is one of their measures of the negative shocks, it is legitimate to examine their findings. These authors compare the US, Canada, and France. As mentioned previously, they first show that the diffusion of computers is approximately identical in these three countries. Then, they construct age-education cells for each sex using the CPS for the US, the 1981 Survey of Work History (SWH), the 1988 labour market activity survey to build the cells, and the 1989 General Social Survey (GSS) to measure computer use for Canada, and various *enquête emploi* from the eighties for France. Then, they estimate the following equation using all cells, separately for men and women:

$$(5) \qquad \Delta \log w_j = d_3 + \frac{\lambda \beta}{\sigma + \varepsilon} dem_j - \frac{\lambda}{\sigma + \varepsilon} \Delta \log f_j + e_j ,$$

in which w is the wage, *dem* is the negative demand shock affecting group j (measured by the share of computer users in group j), σ is the elasticity of the substitution between groups in the production function, ε is the labour supply elasticity, λ is a rigidity parameter (equal to zero for complete rigidity and to one for complete flexibility), f_j is the proportion of group j in the population, and e is a statistical residual. Table 7 contains most of their results. They indeed show that in the US, wage changes for both males and females in a cell are strongly positively related to the proportion of computer users in that cell. However, in Canada, there is no significant relation between wage changes and computer use in the eighties (once more, this applies to men and women). Finally, and even more surprising, the opposite appears to be going on in France. Wage growth is negatively related to computer use. The coefficient is marginally significant for males but it is very large for females. Hence, those who were supposed to be most affected by the negative shocks, i.e. the low-tech workers have had larger wage increases than their high-tech counterparts. We will come back to these results while presenting Goux and Maurin (1997).

We now discuss the evidence on the impact of computer use on employment, skill composition of the workforce, and unemployment.

3. COMPUTERS AND EMPLOYMENT IN THE US AND WESTERN EUROPE

3.1 Evidence from individual-level data

In the US, the only empirical evidence on the relation between employment—skill composition of the plants, to be more precise—and computer use comes from Doms, Dunne, and Troske (1997). The methodology and the data used are identical to the one described in the previous section. Their dependent variables are, of course, slightly different but all explanatory variables are indeed identical to those used for wages. First, Doms, Dunne, and Troske examine the educational and occupational mix in their plants in relation to technology. Their measures are the per cent of workers with at least a college degree, this measure is further decomposed into production and non-production workers; the per cent of workers in managerial, scientific, or engineering occupations; and the per cent of non-production workers. Apart from the non-production workers, all these categories are more frequent in high-technology plants. When looking at the period 1977 to 1992, the change in the non-production labour share is not related to the technologies utilized in the plant. Other ways of measuring changes in the techniques used at the plant (see above) give identical results. The change in the share of non-production workers is not related to the magnitude of the changes in technologies used at the plant between 1988 and 1993. In an attempt to reconcile these results with those already presented (Autor, Katz, and Krueger 1997), the authors match their data with the 1992 Annual Survey of Manufactures (ASM) in which a measure of computer investment is available. The number of plants in these regressions is 1,844 (see their Table VII). While the changes in wages are not related to computer investment, the change in the non-production labour share (from 1977 to 1992) appears to be positively related to computer investment. Evaluated at the mean of the sample, the estimated coefficient implies that computer investment can explain 16 per cent of the growth in non-production workers.

Apart from the United States, direct micro-econometric evidence on the relationship between employment and computer use can only be found in the UK and in France.

In the UK, Machin (1996) uses the panel dataset version of the WIRS, the British Workplace Industrial Relations Survey, for years 1984 and 1990. The dataset contains 402 plants. Besides the standard questions of the WIRS, we know whether a plant has introduced computers between the two survey dates. Hence, Machin examines the changes in the skill composition and finds that the introduction of computers into the plant is associated with an increased share of managers and technicians as well as a decreased share of unskilled manual workers.

For France, Greenan, Mairesse, and Topiol-Bensaïd (1998) find results that are similar to those observed in the UK, i.e. increased computer investment is associated with a decrease in the share of blue-collar workers.

Second, the study of Entorf, Gollac, and Kramarz (forthcoming) does not examine the skill composition but looks directly at the protection effect of computer use, i.e. if computer users are less likely to lose their jobs when the firm faces a downturn. These authors focused upon selection ideas: computer users were not only selected among the pool of workers, but also had already been selected since they were high-wage workers even before using computers. To delve further into the selection effects of computers and other new technologies, Entorf, Gollac, and Kramarz examine the protection effect of computers from job losses. In particular, if computer use implied some training costs that the firm has to recoup or, alternatively, if the mere use of the computer has improved worker *i* quality, computer users will be protected from unemployment relative to non-users.

If we denote $unemp_{it} = 1$ the fact that worker *i* is unemployed at date *t* (after t_0), the authors estimate the following equation:

$$(6) \qquad Pr\left[unemp_{it} = 1 \mid e_{it_0} = 1 \right] = \Phi(\alpha \, Comp_{it_0} + X_{it_0} \, \beta)$$

where X_{it_0} are observables for worker *i*, where $e_{it_0} = 1$ denotes that worker *i* was employed at date t_0, and where Φ denotes the probit function (standard normal c.d.f.). They use the 1993 supplement to the Labour Force Survey on New Technologies (see data appendix) together with the Quarterly Labour Force Survey of the same year. This quarterly survey checks all those workers surveyed in the main March LFS for their employment status in June, September, and December of the same year. The number of workers slightly decreases (from 9,345 to 8,288) but the data appears very close to the initial one. Of those workers employed in March, 1.2 per cent in June, 2.1 per cent in September, and 2.8 per cent in December are no longer employed. Notice that 1993 is a trough in the French cycle. The resulting estimates are clear. Computer users are protected from the risk of a job loss in the short-run. But the protection effect decreases with time, i.e. it is strongest in June, intermediate in September, and disappears in December. Other new technologies do not offer similar protection. Using the matched employee-employer aspect of the data, the authors try different robustness checks, in particular for selection biases. First, they include information on computer use of co-workers—workers employed in the same firm—in a selection equation and, then, include a Mills ratio-type term in the Probit equation. They also compute the person fixed effect from equation (2) and introduce it as an additional regressor in equation (6). Finally, they use the match with the DMMO data (see appendix) to control for establishment-specific business shocks. None of these checks yield a result that differs from the one presented above. Hence, on top of selection, the mere use of a computer protects a worker from job loss and unemployment in the short-run. However, this protection effect disappears as soon as bad business conditions last.

3.2 Evidence from industry, education, or occupation cells

The set of papers that analyse the recent transformations in the demand for skills due to technological shocks is almost identical to the one presented above which mainly examined relative wage changes or changes in the structure of the wage bill shares. The techniques used are exactly identical.

Mishel and Berstein (1996) try to explain education upgrading, i.e. the declining share of high school graduates in American industries. Remember that all these authors focus on within-industry shifts (Katz and Murphy 1992) among others have demonstrated that most changes in the eighties occurred within industries). These authors claim that no obvious conclusion emerges from their results. All estimates are small and many are even statistically insignificant. They find that the impact of technology for both males and females is small quantitatively and statistically.

Autor, Katz, and Krueger (1997) first analyse the annualized change in the fraction of employed workers in each education group between 1979 and 1993. Their results show that 'the shift toward college-educated workers, and away from high school-educated workers, was greatest in industries that experienced the greatest increase in computer use.' As the authors point, the share of college-educated workers increased each year between 1979 and 1993 by 0.36 per cent. Surprisingly, a strong growth in computer use is also associated to a rise in the share of workers with less than high school education in an industry. Autor, Katz, and Krueger try to control for this effect by introducing the 1974 mean education level in the industry, since they argue that this correlation comes from the industries that employed almost no high school dropouts. Notice that this effect remains for females, even after introducing this control. Together, with the evidence presented in the previous section, these authors conclude that the growth of computer use is driving the increased demand of college-educated workers.

Striking to the external reader, these two groups of authors arrive at very different conclusions. First, it seems that the use of a different explanatory variable, the 1984 to 1993 change in computer use as calculated from the CPS, yields different results than those obtained and more cautiously presented by Mishel and Bernstein (1996). Notice also that even when they use the same data, the computer investment variable, differences in specification of the estimated equations seem to yield quite different estimates.

Card, Kramarz, and Lemieux (1997) examine the following equation:

$$(7) \qquad \Delta \log p_j = d_3 + \frac{\lambda\beta}{\sigma+\varepsilon} dem_j - \frac{\lambda}{\sigma+\varepsilon} \Delta \log f_j + e_j ,$$

where p_j is the share of employed workers in each cell j. This second equation supplements equation (5) which analysed wage changes across age-education cells in the analysis. The authors show that in the US those workers in cells who most intensively used new technologies, as measured from computer use, are the same for whom the employment share increased the most. But, surprisingly, for Canada there is no significant relation between computer use, i.e. the measure of the negative shocks that should have affected the low-skills workers, and employment changes. And, even more surprisingly, in France which exhibited the strongest wage rigidity, relative employment changes for females are not related to computer use, while for males, relative employment changes are identical to those observed in the United States.

Hence, it seems that similarity in computer use across countries masks wide differences in other aspects—such as labour market institutions, supply of college-educated workers,...—that may well explain the different patterns observed in various countries. The paper below will present more specific evidence for France.

Goux and Maurin (1997) use a theoretical framework that bears some similarities with Katz's and Murphy's (1992). This framework allows them to decompose changes in employment of different skills in each industry into various components. First, they use the classical between and within-industry decomposition. These two components can be further decomposed into parts coming from international trade, trade surplus, domestic demand changes. For these three subparts, it is also possible to assess the impact of the within-industry changes in the relative costs of the various labour categories. Finally, they propose a way to reconstruct the part due to technical progress using their set of equations and their different decompositions. In some sense, even though it is more structural, their model also resembles the one estimated by Autor, Katz, and Krueger when they analyse skill-upgrading (see above). But Goux's and Maurin's results are extremely different from those obtained by Autor, Katz, and Krueger. First, they find that technical progress is not biased in France. Second, the between-industry movements explain 60 per cent of the observed reallocations while the changes in the relative costs explain the remaining part. Hence, these results are completely at odds with those observed in the US since in France between-industry reallocations are more important while the reverse holds in the US (except in the sixties, see Autor, Katz, and Krueger 1997). In addition, supply effects are also important. Notice that Autor, Katz, and Krueger note that such a result could also obtain in the US if the elasticity of substitution between college and high school-educated workers were equal to 1.0 (or lower) while their preferred value is 1.4. Turning to the impact of the change of technologies and goods produced, Goux and Maurin show that the dominant role is played by the changes in domestic demand and, as a corollary, the absence of impact of international trade on the demand for high school or college-educated workers.

To directly assess the impact of computers and new technologies, Goux and Maurin use the same datasets as Entorf, Gollac, and Kramarz used in their various studies (see the data appendix). In conformity with their theoretical model, they regress their measure of technical change (for the period 1970 to 1993 (model 1) and for the period 1985 to 1993 (model 2)) onto the diffusion rate of the various new technologies, including computers in 1993 for model 1 and onto the change in the diffusion rates of these techniques between 1987 and 1993.

The first model shows that, indeed, those industries and occupations which most intensively use these new techniques in 1993 are also those in which technical progress has been most important. Their estimates imply that an increase of one point in the spread of new technologies increase productivity by 0.30 per cent. In addition, the results confirm that the spread of new technologies explains a part of the shift between industries but none of the shifts between occupations. The second model is in some sense even worse since the estimates show that there is no relationship between technical progress and the spread of computers in the various industries. Furthermore, new technologies have had the same impact on each of the occupations. Fortunately, they are also able to demonstrate that the diffusion of computers is responsible for a fall of 2.5 points in the share of unskilled workers in total employment while new production technologies explain a fall of 0.8 points. Hence, the increased diffusion of new technologies explain only 15 per cent of the labour demand shifts observed between 1970 and 1993. In this respect, Goux's and Maurin's results are completely consistent with those given in Card, Kramarz, and Lemieux (1997).

Apart from the effects of computer diffusion on wages and employment, one can hint that new production techniques, including computers, have had a strong impact on how goods and services are produced. We review some evidence in the following section.

4. COMPUTERS AND THE WORKPLACE ORGANIZATION

Anecdotal evidence on the impact of computers, robots, microprocessors on the workplace organization abound. However, the only statistical evidence on this topic that I am aware of, comes from the United States on one side and from France on the other. The American evidence is presented in Kathryn Shaw (1998). It focuses on the steel industry which Shaw, with her various co-authors, has been examining for some years now. In particular, she has been looking at the relation between new production techniques (mini-mills), information technologies of which computers are an important component, and skill requirements for the employees. Indeed, even though the number of plants surveyed is less than 100, the scope of investigation is large enough to get a sense of some of the potential impacts of computers on workplace organization. Shaw's results can be summarized as follows. Computer use has changed the variety of products that firms are able to produce. This has, in turn, been translated into new requirements for the workers. Most of these changes have been implemented through creation of new plants or firms and exit of older plants. New workplace organization, the so-called innovative human resource management (HRM) practices, go hand in hand with computer use. Workers hired in these new plants appear to be better skilled than those employed in older establishments (even though there appears to exist no direct evidence linking hiring practices and computer use).

The French evidence is much more direct. It has been gathered mostly by Gollac and his team. The basic survey from which results are derived, is called TOTTO-Europe and has been collected in 1994. Approximately 1,000 workers were surveyed, half of whom use a computer at work. The information is much more detailed in many ways than the 1987 or 1993 TOTTO surveys that were supplement to the LFS (see data appendix). For instance, precise information on machines as well as softwares used by the workers, interactions with co-workers in the course of use (help given or received, in particular), precise information on the workplace arrangements, etc. were collected. I will try to summarize the main findings of Gollac (1996), Bonvin, Combessie, Faguer, and Gollac (1994), and Gollac and Kramarz (1997). In particular, I will organize the discussion around two opposite issues: computers induce cooperation, computers facilitate control.

Gollac (1996) studies the impact of computer implementation on the cooperation between computer users within the firm as well as outside it. Using questions from TOTTO-Europe, he analyses the contacts between each person using a computer at work (432 individuals in the sample) and the respective hierarchical superiors, close colleagues, co-workers, the computer department, an outside computer firm as well as other outside firms. Information is collected for each person on the assistance received and given. Based on this information, Gollac shows that it is common for help to be given to or received from the sphere of close colleagues with whom the worker is associated everyday. Interestingly, in addition to this close environment, the low-skill, low-education workers receive help relatively more often from their hierarchical superiors while high-skill, high-education workers receive help more often from outside (from other colleagues, outside firms, or even friends), particularly if they normally have business contacts with these individuals (for data exchange, for instance). Using very detailed information on the type of computerized task that each user performs (type of software, in particular), Gollac also shows that workers performing complex tasks more often receive distant help (outside the firm). Hence, computer use on the one hand can increase cooperation within the firm for high or middle-skilled workers while on the other hand, some low-skill workers can find themselves in a difficult situation if they cannot organize a network of colleagues around them when computers are implemented.

Bonvin, Combessie, Faguer, and Gollac (1994) and Gollac and Kramarz (1997) provide evidence on the relationship between computers and supervision or promotions. In TOTTO-Europe, information has been collected on the influence of individual effort on wage or promotion, on the existence of individual evaluation interviews (including the use of measurable criteria), on the existence of an individual notation. These authors show that, whenever a worker had a positive answer to any of these questions, the use of a computer use is more probable (see Table 1 of Gollac and Kramarz 1997 for instance). This result holds for all skill-levels. In fact, and consistently with the longitudinal results presented in Entorf and Kramarz (1997 and 1998) or Entorf, Gollac, and Kramarz (forthcoming), very few workers (less than 10 per cent) say that they receive a bonus directly because they use a computer. So, computer use does not directly and rapidly affect wages, but may still affect the way workers are evaluated, and even more so when computers can transform the manner in which supervision is conducted (see the sociological evidence based on multiple interviews in Bonvin, Combessie, Faguer, and Gollac 1994).

All statistical evidence seems to support ideas expressed in Bresnahan (1997) or in the conclusion of Entorf, Gollac, and Kramarz (forthcoming) that interpersonal skills (what Bresnahan calls noncognitive skills) seem to be most important in a period of rapid diffusion of computers; these skills are complements to computer use. But, more research must be devoted to these issue of the internal organization of the firm in a highly computerized environment.

5. CONCLUSION: SHOULD WE BELIEVE IN SKILL-BIASED TECHNICAL CHANGE?

5.1 A discussion of the above evidence

All evidence presented seems to point to the following conclusion. Something is going on, but there is no reason to call it skill-biased technical change in its simplest interpretation. Otherwise, why should we observe such different trends in the United States and in Europe? The computer is used everywhere in the developed countries, and the diffusion rates are roughly equal. Furthermore, the machines and the softwares used are increasingly similar and delivered simultaneously. Hence, trends on the various labour markets, if these are mostly caused by technical change, should also be very similar. This does not seem to be what is happening in the Western world. If we accept some of the results presented (Goux and Maurin 1997 for France, together with those of DiNardo, Fortin, and Lemieux 1996), institutions with classical supply and demand factors should be able to explain a large fraction of the facts observed.

5.2 Implications for developing countries

If the reader believes the above premises, the impact on developing countries must be seen from two viewpoints. First, one must examine the various institutional arrangements—minimum wages, unions and collective bargaining, etc.—that prevail in the countries as well as supply of high school or college-educated workers which are likely to affect the wage and employment structure. Second, one must be aware that the evidence of the influence of computers on workplace organization and, more generally, on the internal organization of the firm is almost certainly going to be worldwide. All firms in the developed or developing countries will face the same challenge of transforming the workplace to make the firm function efficiently with computers and workers simultaneously present. Obviously, computers and telecommunication tools should not be separated in the analysis. This means that training at school but, more importantly, within the firm is a crucial means of upgrading the skills of workers so that they can adapt their technical but also behavioral and interpersonal skills to this fast diffusion of computers.

DATA APPENDIX

In France, Entorf and Kramarz (1997 and 1998) have used the following type of data in which they match four different INSEE sources. The basic sources are the *Enquête Emploi*, 1985-87, a wave of the French Labour Force Survey, and the *Enquête sur la Technique et l'Organisation du Travail auprès des Travailleurs Occupés* (TOTTO) of 1987, an appendix to the labour force survey that asked questions about the diffusion of new technologies and the organization of the work place. Besides questions usually present in labour force surveys (wage, tenure, age, education, etc.) the appendix contains a rich source of information on the use (e.g. intensity, experience) of microcomputers, terminals, text processing, robots and other well specified groups of 'new technology' labour. Likewise, questions concerning the hierarchy of labour and working-time schedules help in drawing more detailed conclusions concerning the impact of new technologies than would be possible by the analysis of usual labour force surveys.

Furthermore, the employing firms in the datasets can be known since the standardized Siren enterprise identification number has been coded for the first time in an INSEE survey for this particular year (1987) and survey (TOTTO). Each number represents the enterprise at which the individual is employed. This feature of the French INSEE classification system enables the researcher to employ information from corresponding firm-level surveys (skill structure, profits and share of sales going to exports, for instance) over the 1985-87 period.

The survey *Enquête sur la Technique et l'Organisation du Travail auprès des Travailleurs Occupés* (TOTTO) was performed in March 1987. It covers a total of about 20 million individuals in civilian employment. The probability of being selected is 1/1000; thus the survey contains about 20,000 workers. Questions concerning the organization of the workplace were asked to wage-earners and salaried employees only, questions concerning the use of 'new technologies' were asked to all members (including civil-servants) of the civilian work force (according to the definition of the OECD). The sample used for cross-section estimation consists of 15,946 wage-earners and salaried employees, based on TOTTO. The longitudinal sample where individual workers are followed at least two years and at most three years has 35,567 observations. When merged with firm-level information, the cross-section dataset includes 3,446 individuals and the longitudinal dataset reduces to 7,965 observations. The firm-level data are based on a panel of firms covering the years 1978 to 1987, the *Echantillon d'Entreprises* (EE). The firm-level information comes from an exhaustive sample for large firms (more than 500 employees) and an INSEE probability sample plan for smaller firms. The sample plan provides a weighting variable which is used in subsequent estimation in order to estimate the variance-covariance matrix that is representative of the population of individuals (such that the bias arising from the higher probability of large firms to be in the sample can be offset).

In 1990 started a new series of March *enquête emploi* with a sampling frame based on the 1990 census. The sample corresponds to a sampling ratio of 1/300 and is renewed by one-third every year. Hence, every individual is at risk of being surveyed at most three consecutive years. Furthermore, the sampling technique is based on housing in tracts built in French territory with the further inclusion or modifications in case of construction or reconstruction of buildings not known at the 1990 census (see INSEE, 1994 for all the technical details on the survey methodology). This introduction of new buildings (and households) is made by interviewers, who are responsible for a sub-tract and interview the members of each household.

Each year, a supplement (*enquête complémentaire*) is directed at the outgoing third of the sample. Standard questions from labour force surveys are also present. Hence, besides the wage, we know the country of origin, the sex, the marital status, the number of children and their age, the region of residence, the age, the detailed education and the age at the end of the education period, the occupation (4-digits classification), father's last occupation, mother's last occupation, the employment status (employed, unemployed, inactive), usual number of hours, the seniority in the employing firm, the sector and size of the employing firm, the nature of the contract (short-term, long-term, programme for young workers (stage)) for each of the individuals in the sample. Furthermore, each employed individual is asked about his (her) firm every year (in contrast to the 1987 survey). Name, address, is collected as often as possible. This information is given to the INSEE regional agencies where the SIRET (establishment identification number) is coded using the on-line SIRENE computerized system. This number is the unique establishment identifier that an establishment receives during its life. As already mentioned, the first nine digits represent the firm to which the establishment belongs. This number can be coded in the *enquête emploi* for more than 90 per cent of the workers. Hence, it becomes possible to match with other firm level datasets as the *Echantillon d'Entreprises* (EE) see above or the *Déclaration de Mouvements de Main d'Oeuvre* (DMMO), a record of all entries and exits in all establishments with at least 50 employees.

In the US, the Longitudinal Research Database (LRD)—a panel of manufacturing firms—has been linked by K. Troske with the 1990 Decennial Census. In France, the supplement of the 1987 Labour Force Survey on New Technologies contains the firm identifier, the Siren number, for most employed worker that has allowed matching with the *Echantillon d'Entreprises* (EE), a dynamically representative sample of French firms.

We first describe the Worker-Establishment Characteristics Database (WECD) (the description is based on Troske, forthcoming). The data for workers comes from the 1990 Sample Detail File (SDF) which consists of all households questionnaires of the 1990 Decennial Census long form. As for establishments, the data come from the 1990 Standard Statistical Establishment List (SSEL), a register of all establishments active in the US in 1990. From the SSEL, a 4-digit SIC code giving the establishment primary industry and a geographic code giving location are drawn. All manufacturing establishments were kept. Equivalent information is obtained for the individuals in the SDF through individual responses coded by the Census Bureau (with different industry codes, however). All workers employed in manufacturing in 1990 who responded to the long form are in the sample file. The number of individual observations is 4.5 millions. The matching procedure comprises four steps. First, Troske standardized the geography and industry definitions across the two data sources. Second, he eliminates all establishments that are not unique in each location-industry cell. Third, he gives a unique establishment identifier to all workers that are located in the same location-industry cell. Fourth, all matches based on imputed data are eliminated.

The resulting dataset contains 200,207 workers employed in 16,197 plants. Troske (forthcoming) describes various tests of the quality of the WECD which appear to be conclusive. On average, 16 per cent of an establishment's workforce is included in the WECD. It is the number of matches that should follow given the sampling frame of the SDF. Different measures of earnings coming from individual data aggregated at the establishment level and from establishment data are positively and significantly correlated. An analysis of the structure of the establishments shows that large plants and plants located in urban areas are overrepresented in the WECD. This induces overrepresentation of white, male, educated workers in comparison to the original SDF data.

REFERENCES

Asplund, R. (1997). 'The Disappearing Wage Premium of Computer Skills'. ETLA Discussion Paper 619. Helsinki, Finland.

Autor, D. H., L. F. Katz, and A. B. Krueger (1997). 'Computing Inequality: Have Computers Changed the Labour Market?' NBER Working Paper 5956.

Bartel, A. P., and N. Sicherman (1996). 'Technological Change and Wages: the Roles of Ability, Schooling, and Training'. Columbia University Working Paper.

Bell, B. D. (1998). 'Skill-Biased Technical Change and Wages: Evidence from a Longitudinal Dataset'. Forthcoming in *Industrial and Labour Relations Review*.

Berman, E., J. Bound, and Z. Griliches (1994). 'Changes in the demand for Skilled Labour within US. Manufacturing Industries: Evidence from the Annual Survey of Manufacturing'. *Quarterly Journal of Economics* 109: 367-98.

Bonvin, F., J. C. Combessie, J. P. Faguer and M. Gollac (1994). 'Une Machine qui Change la Vie?' CEE Working Paper 9424.

Bound, J., and G. Johnson (1992). 'Changes in the Structure of Wages in the 1980's: An Evaluation of Alternative Explanations'. *American Economic Review* 82 (3): 371-92.

Bresnahan, T. F. (1997). 'Computerization and Wage Dispersion: an Analytical Reinterpretation'. Stanford University Working Paper.

Card, D., F. Kramarz, and T. Lemieux (1997). 'Changes in the Relative Structure of Wages and Employment: A Comparison of the United States, Canada, and France'. NBER Working Paper 5487.

Chennels, L., and J. Van Reenen (1998). 'Technical Change and the Structure of Employment and Wages: A Survey of the Microeconometric Evidence'. IFS working paper.

DiNardo, J. E., and J. S. Pischke (1997). 'The Returns to Computer Use Revisited: Have Pencils Changed the Wage Structure Too?' *Quarterly Journal of Economics* 112: 291-304.

DiNardo, J. E., N. M. Fortin, and T. Lemieux (1996). 'Labour Market Institutions and the Distribution of Wages, 1973-1992: A Semi-Parametric Approach'. *Econometrica* 64: 1001-44.

Doms, M., T. Dunne, and K. R. Troske (1997). 'Workers, Wages, and Technology'. *Quarterly Journal of Economics* 112: 253-90.

Entorf, H., and F. Kramarz (1997). 'Does Unmeasured Ability Explain the Higher Wages of New Technology Workers'. *European Economic Review* 41: 1489-510.

Entorf, H., and F. Kramarz (1998). 'The Impact of New Technologies on Wages and Skills: Lessons from Matching Data on Employees and on their Firms'. *Economics of Innovation and New Technologies* 5: 165-97.

Entorf, H., M. Gollac, and F. Kramarz (n.d.). 'New Technologies, Wages, and Worker Selection'. Forthcoming in *Journal of Labour Economics*.

Feenstra, R. C. (1996). 'US Imports, 1972-1994: Data and Concordances'. NBER Working Paper 5515.

Feenstra, R. C., and G. H. Hanson (1996). 'Globalization, Outsourcing, and Wage Inequality'. *American Economic Review* 86: 240-45.

Gollac, M. (1996). 'Le Capital est dans le Réseau: la Coopération dans l'Usage de l'Informatique'. *Travail et Emploi* 68: 39-60.

Gollac, M., and F. Kramarz (1997). 'L'Ordinateur: un Outil de Sélection?' *Revue Economique*: 1115-41.

Goux, D., and E. Maurin (1997). 'The Decline in Demand for Unskilled Labour: an Empirical Analysis Method and its Application to France'. INSEE Working Paper.

Greenan, N., J. Mairesse, and A. Topiol-Bensaïd (1998). 'Information Technology and R&D Impacts on Productivity and Skills: A Comparison on French Firm-Level Data'. Paper presented at the UNU/WIDER meeting on Information Technology and Economic Development, 12-13 June, Helsinki.

Katz, L. F., and K. M. Murphy (1992). 'Changes in Relative Wages, 1963-1987: Supply and Demand Factors'. *Quarterly Journal of Economics* 107: 35-78.

Krueger, A. B. (1993). 'How Computers Have Changed the Wage Structure: Evidence from Microdata, 1984-1989'. *Quarterly Journal of Economics* 108: 33-60.

Lowe, G. S. (1991). 'Computers in the Workplace'. *Perspectives on Labour and Income* 3 (Summer): 38-50.

Machin, S. (1996). Changes in the Relative Demand for Skills in the UK Labour Market. In A. Booth and D. Snower (eds) *Acquiring Skills.* Cambridge: Cambridge University Press.

Machin, S., and J. Van Reenen (1998). 'Technology and Changes in Skill Structure: Evidence from an International Panel of Industries'. UCL Working Paper.

Mishel, L., and J. Bernstein (1996). 'Technology and the Wage Structure: Has Technology's Impact Accelerated Since the 1970s'. Economic Policy Institute Working Paper.

Murphy, K. M., W. C. Riddell, and P. M. Romer (1998). 'Wages, Skills and Technology in the United States and Canada'. In Elhanan Helpman (ed.) *General Purpose Technologies*. Cambridge, MA: MIT Press.

OECD (1998) 'Use of Information and Communication Technologies at Work. OECD, DSTI/ICCP/IE(97)8/FINAL.

Reilly, K. T. (1995). 'Human Capital and Information'. *Journal of Human Resources* 30: 1-18.

Shaw, K. (1998) 'By What Means Does Information Technology Affect Employment and Wages?' Paper prepared for the conference on Information and Communication Technologies, Employment, and Earnings, Nice, June.

Troske, K. R. (1997). 'Evidence on the Employer Size-Wage Premium From Worker-Establishment Matched Data'. US Census Bureau Working Paper.

Troske, K. R. (forthcoming). 'The Worker-Establishment Characteristics Database'. In (eds) J. Haltiwanger, M. Manser, and R. Topel *Labour Statistics Measurement Issues.* Chicago University Press for the NBER.