British Journal of Industrial Relations
39:2 June 2001 0007–1080 pp. 257–284

A New Voice or a Waste of Time? Wage Premiums from Using Computers for Communication in the UK Workplace

Andrew K. G. Hildreth

Abstract

The paper uses the Workplace Employee Relations Survey data on workers to investigate the wage premium from using e-mail in the workplace against other more traditional forms of communication. I try to discern whether the existence of a premium from using e-mail is the product of the workplace encouraging worker productivity through voice, or represents unobserved worker skills in using new technology. Results indicate that any observed premium from using e-mail is likely to arise from unobserved worker skills, and that any premium associated with voice in the workplace is likely to result from management choosing to reward such worker involvement.

1. Introduction: computers and voice within the workplace

A great deal has been made in recent years of the skill-biased technological change argument for explaining the divergence in wages across individuals. The basic tenants of the argument are that the increasing demand for technologically-skilled labour has lead to a wage premium for workers able to use the new technology; that the new technology makes a worker more productive than one not using the new technology; and that as a result the earnings such workers receive are higher. Most of the research in this area has used data at the individual worker level. This paper proposes to examine the role of the workplace in providing e-mail, and the impact this has on certain sections of its work-force.

Estimating the role of the computer in its implications on pay started with Krueger (1993). Krueger observed that, controlling for the usual range of demographics and workplace characteristics, workers using a computer at work earned, on average, 15–20 per cent more than those who did not. The

Andrew K. G. Hildreth is at the CCRDC and the Department of Economics, University of California-Berkeley. E.mail:hildreth@econ.Berkeley.edu

same wage premium existed if the main computer use was e-mail. This was compared against using the computer to play games, which brought with it a negative wage premium. The substantial wage premium to productive computer use was simply the result of being presented with a computer to use, rather than from any particular selection effect on the part of the individual workers. Subsequent authors have found that there are returns arising from increasing the technology available for the work-force. Autor *et al.* (1998), Haskel (1999), Machin and Van Reenen (1998) and Van Reenen (1996) have all found that technology helps increase the wage for workers, when compared with workers who do not have access to the productivity-improving machines. Dissenting voices have been given by DiNardo and Pischke (1997) and Entorf and Kramarz (1997).[1]

Arguments against the notion of there being a return from using computers (or technology) at the individual worker level have centred around the selection of individuals and employers to use the new technology. One way to examine this is to compare the returns to individuals from using computers with returns from using other workplace tools. DiNardo and Pischke (1997) use German data on workplace tools, and examine the returns from using computers against those arising from the use of telephones, pens or pencils. They find that there are similiar returns from using computers as from using pens and pencils. Given the level of literacy in Germany, it is difficult to believe that the skill of using a pencil is in short supply, and therefore commands a premium. What is really needed to examine the problem of a return from technology implementation in the workplace is data on both workers and employers. Entorf and Kramarz (1997) use such data, for a sample of French workers and employers, over time. They were able to examine when an employer adopts a new technology, and which worker then works with it. They found that it is the more able workers who work with the new technology.[2] These workers earn a premium because they have higher unobserved ability that is correlated with computer use, and this correlation gives the observed premium on working with new technology. Even in the event of no new technology being introduced, workers with a high unobserved ability would have received a premium.

It is not immediately obvious why the use of e-mail, or any means of communication for 'voice' at the workplace, should provide a wage premium. 'Voice' was described by Hirschman (1970) as 'information-rich', where instructions are able to be given from one side to the other. Where 'exit' has just one outcome — the individual leaves the firm — 'voice', in terms of a return for the individual, may have two outcomes. The first is that those who raise their voice may be penalized within the organization if voice is seen as criticism; in this instance workers may earn less if they use e-mail. The second is that voice has beneficial effects within the workplace, in that being able to add their voice to the organization helps to maintain workers' loyalty and encourages workers to be productive within the firm. Accordingly, the workers receive the benefits of such an exchange in terms of higher pay.

More recently, Bresnahan (1999) has called into question the approach of simply examining who gets a computer and who does not in seeking to determine if there is a premium to computer use. If computers are used as a new voice in the workplace (e-mail), then there must be a reason why it is more efficient to use them. Employers don't simply buy a computer and place it on someone's desk: the computer, especially if it is to be used for communication purposes, has to be integrated into the workplace. This integration will be reflected in workplace performance, as well as the type of workers the employer now requires and the remuneration for workers in particular types of job.

Specifically, Bresnahan (1999) suggests that the matter of importance is not which individual is given a computer for use, but rather, how computers are used in an organizational context. The organizational computing theory predicts events at the workplace level. The extent to which we may observe a return to e-mail across individuals, and across workplaces, depends on the type of industry, the need for communication within the firm, the type of employees the company has and the type of employees the company requires. A high use of e-mail within a workplace would occur only in two instances. The first is a substitution argument. If the firm is a high-communication workplace, then the communication needs of the firm have begun to be met by the introduction of e-mail for some lower-order cognitive tasks formerly performed by employees. In time, if low-cognitive-ability type workers are not available, more and more of the tasks that such workers have performed in the past may be carried out by higher-cognitive-ability workers using e-mail. For example, managers may be able to co-ordinate via e-mail rather than using an assistant. Secretarial or clerical workers would be observed to receive no wage premium from e-mail use.

The second argument is one of complementarity. Once again, for high-communication workplaces, an observed wage premium would be observed for workers with people skills using e-mail. For example, managers able to co-ordinate effectively using e-mail would be observed receiving a wage premium. In this instance, e-mail cannot replace workers, as the wage premium indicates a different sort of return from using the computer for communication. More workers with people skills would have to be hired to reduce the wage premium to these workers; it is not possible to replace some of their tasks with the technology.

This paper presents an examination of the returns from using e-mail as a voice mechanism, and the implications for the workplace, for Great Britain. Using the WERS (Workplace Employee Relations Survey) for 1998, questions were presented to a random draw of employees in each workplace on (among other things) pay, demographics and how information was communicated to the work-force. This last subject details e-mail use against other forms of communication (meetings, noticeboards, newsletters). Evidence on the information flow through the workplace is examined to investigate whether information is given by management and used as a monitoring device, or is shared throughout the workplace. The presence of

e-mail, and the potential returns from its use, are examined at the workplace level. Further analysis is also carried out on the implications for the type of worker that may receive the wage premium and the implications for the workplace in which type of worker is being hired. Finally, using other workplace variables on technology and consultation with the work-force, it is possible to try and separate out the 'voice' mechanism part of computers from their other uses within the workplace.

The paper is organized in the following manner. Section 2 describes the data and the model. Section 3 presents the results on the returns from different methods of communication within the workplace. The results show that any returns from using e-mail are the product of workers with higher unobserved skills using computers. These unobserved skills are associated with different types of job. For example, managers who use e-mail also need people skills,[3] managers earn an observed premium from using e-mail because it is associated with people skills. Likewise, establishments that have a high e-mail use also have trouble recruiting managers. From using other variables on new technology introduction and communication between workers and management, it appears that e-mail use and new technology introduction are separable in their effects on pay. What matters in using e-mail as a voice, if there is any effect at all, is the incentive structure for supplying information within the workplace.

2. The Workplace Employee Relations Survey (WERS): data and model

Data Description

WERS provides the ideal data set from which to examine the issues presented in the Introduction because of the relevance of the survey to establishments, and because of the number of workers surveyed per establishment.[4] The aim of the survey is to provide detailed information on the organization of management–employee relations within a random sample of establishments, and on the impact of this on employer performance (see Cully *et al.* 1999). Upon completion of the management interview, permission was sought to survey up to 25 employees per workplace. The information required from the workers concerned demographic characteristics, education, tenure at the workplace, training, occupation, hours, union association and pay.

The sample used for this paper was restricted to private-sector workplaces. To test for a wage premium is to suggest that underlying the premium is the ability to increase worker productivity and to earn rents from doing so. The proposition that the employer would earn rents is tested in a later section. The number of workers in private-sector establishments, as shown in Table 1, is approximately 14,000 once allowance has been made for complete responses.[5] The number of private-sector establishments giving complete replies was 1509. This allows a large number of workers per establishment. On average, there were 18 workers per establishment. The identification of

unobserved establishment effects is possible only if there are two or more workers observed at each establishment. Appendix A contains further details. Most of the sample of workers (about 97 per cent) are of two or more workers observed at each establishment.

Workplace variables, from the Management Questionnaire, concerned the ownership and control of the workplace (Section A), the consultation and communication within the workplace (Section D), performance at the workplace (Section K) and the degree to which it had implemented any new technology or management practices in the past five years (Section L). Most of the Employee Questionnaire was used, especially the question concerning how a worker keeps up-to-date about the workplace. The question B6 on the Employee Questionnaire asked: 'How helpful do you find the following in keeping up-to-date about this workplace?' Four communication methods were listed: noticeboards, e-mail, the workplace newsletter or magazine, and meetings of managers and employees. To each of these four methods there were five responses: 'very helpful', 'helpful', 'not very helpful', 'not at all helpful', and 'not used here'. The responses were re-coded into a binary response of 'used here' and 'not used here'. The degree to which a particular communication device was useful was not considered.

As the response to the question regarding information acquisition was made by individuals, the response of 'not used here' was taken as 'not used by me'. The results in this paper refer to individual worker wage equations. Inferring that 'not used here' is the same as 'not used by me' seems reasonable in that there is little reason to expect all workers to use the same communication method. Workers on the shop-floor, or those who are part of a sales department, might use a different communication method from administrative or managerial staff.

Table 1 provides a basic set of means for the sample of matched worker–employer observations that were used. The table illustrates how workers using e-mail, against other forms of communication, differ in their observed attributes and the workplaces in which they work. In terms of unconditional means, workers using e-mail are younger, have more employer training, are better educated, are more likely to work in white-collar jobs (management, professionals, associate professionals and technical, and clerical and secretarial jobs), are to be found in certain industries (energy, finance, business/computing), in larger workplaces and for companies that are financially more successful.

As the question on the type of communication method used to keep up-to-date about the workplace referred only to a 'top-down' information flow, further checks were carried out to determine whether the e-mail used by workers was part of an information flow throughout the workplace. In particular, three questions at various points of the Management Questionnaire were combined to form a single index. (1) From Section A (Background) of the questionnaire, managers were asked about their views concerning employee relations issues; question 10 concerned decisions made by management without consulting employees. (2) From Section D

TABLE 1
Mean Characteristics of Private-Sector Workers and Employers, by Method of Communication

Variable	*Total*	*e-mail*	*Meetings*	*Noticeboard*	*Newsletter*
Predicted weekly pay[a]	271.73	280.34	234.75	224.08	234.40
Workers less than age 40	0.557	0.583	0.567	0.563	0.567
Workers with less than 5 years' tenure	0.548	0.537	0.542	0.539	0.530
Workers with less than 5 days' training	0.413	0.466	0.442	0.426	0.454
Union recognized	0.426	0.479	0.455	0.457	0.517
Union members	0.283	0.293	0.300	0.301	0.338
Female	0.461	0.437	0.455	0.459	0.448
O levels	0.271	0.258	0.270	0.273	0.274
Degree	0.158	0.230	0.175	0.160	0.167
Managers/senior administrators	0.128	0.188	0.149	0.130	0.138
Professionals	0.096	0.153	0.109	0.099	0.103
Associate professional/technical staff	0.074	0.107	0.081	0.075	0.078
Clerical/secretarial	0.227	0.284	0.228	0.227	0.241
Craft/skilled services	0.098	0.060	0.089	0.095	0.091
Personal/protective services	0.047	0.019	0.045	0.045	0.035
Sales	0.118	0.089	0.118	0.121	0.133
Operative/assembly work	0.130	0.064	0.118	0.136	0.116
Other occupations	0.079	0.035	0.061	0.071	0.063
Manufacturing	0.218	0.198	0.217	0.227	0.199
Electric/gas/water	0.059	0.107	0.069	0.063	0.084
Construction	0.051	0.032	0.044	0.043	0.041
Wholesale retail trade	0.187	0.161	0.181	0.192	0.199
Hotels/restaurants	0.059	0.041	0.058	0.060	0.054
Transport/telecommunications	0.072	0.068	0.069	0.074	0.082
Finance	0.085	0.113	0.098	0.090	0.107
Business/computing	0.125	0.179	0.121	0.111	0.120
Public administration	0.001	0.001	0.001	0.001	0.001
Education	0.033	0.030	0.033	0.032	0.026
Health/social work	0.071	0.033	0.075	0.073	0.055
Other	0.038	0.037	0.036	0.035	0.032
PLC	0.572	0.632	0.598	0.595	0.667
Financial performance	2.28	2.65	2.27	2.27	2.24
Labour productivity	2.42	2.42	2.41	2.41	2.38
Size of workplace	115	148	122	122	145
No. of observations	13780	6041	11122	12400	9426

[a] The pay variable refers to predicted pay, assuming a normal distribution, and conditioned on age, union association, tenure, training, education, hours/week worked, married, female, health, race, occupation, industry, size of workplace, franchise, profit-related pay, assessment on individual performance and whether a PLC or a single-establishment firm.

(Communication and Consultation) of the questionnaire, there are detailed questions concerning how managers at a workplace communicate with employees; the response to one multiple-choice question was that information was supplied to employees via a systematic management chain (or a cascading of information). (3) Finally, from Section K (Performance at the Workplace), managers could respond to the question on monitoring the quality of work at the workplace by replying that it was their responsibility. These three measures were then added to provide an overall measure, termed a 'sinister index': whether managers monitored worker performance,

consulted with workers, and/or believed that the reported information flow for management was down to the workers.[6]

Table 2 provides the results for information flow and the method of communication used by the workers. The table provides the correlation coefficients for the method of communication and the information flow measure. It also reports whether the correlation is significant. The significant negative correlation in the results in Table 2 shows that e-mail is used in workplaces where managers do consult with workers, and where managers do not tell the workers what to do (the 'sinister index'). This is compared with other methods of communication, where there is more reason to believe that managers do restrict the information flow from the top down, although other measures of information flow are not significantly correlated with the information flow measure. While the results are weak, if anything they indicate, either together or individually, that e-mail (or any of the other communication techniques) is concerned more with allowing feedback than with simply imparting information.

Identifying whether or not using e-mail, or attending meetings, makes a difference to worker remuneration, both between and within establishments, is possible, as workers matched to establishments did not give completely consistent answers. Workers within a workplace did not *all* attend meetings, or *all* use e-mail, look at noticeboards or read newsletters to keep up-to-date about the workplace. The largest degree of within-establishment variation was in using e-mail. In total, in 906 establishments, not all the work-force used e-mail as a means of communication; in 122 workplaces all employees did use e-mail. The corresponding figures for meetings were 873 and 300. There was less variation for noticeboards and newsletters. The predicted

TABLE 2
Correlation of Information Flow within the Workplace and Method of Communication

Information flow measure	*e-mail*	*Meetings*	*Noticeboard*	*Newsletter*
No consultation with workers by management	−0.076 (0.000)	−0.147 (0.000)	−0.096 (0.001)	−0.125 (0.000)
Information flow from management down	0.013 (0.119)	0.237 (0.000)	0.223 (0.000)	0.272 (0.000)
Managers monitor worker performance	0.025 (0.377)	−0.013 (0.664)	−0.014 (0.622)	0.030 (0.307)
'Sinister Index' (additive index of above criteria)	−0.035 (0.000)	−0.029 (0.326)	0.040 (0.164)	0.003 (0.921)

Notes
Figures in parentheses are significance values. A value less than 0.05 indicates that the correlation rejects the null of zero correlation between the two measures at the 95% confidence interval.
No. of observations = 1509.
The method of communication refers to the average number of workers at the workplace using that method.

conditional wage variable (see Hildreth 1999) shows that, for private-sector establishments using e-mail and meetings, the greatest degree of wage variation comes from within the establishment rather than between them. Higher wages are associated with communicating by e-mail within an establishment, compared with workers within the same workplace who were not using the e-mail system. For establishments using noticeboards and newsletters, there was little difference in the wage variation within the workplace, compared with between different places of work.

The Econometric Model

As WERS provides a great deal of detail on both the employer and the worker, the basic model for the work presented in this paper is an extended human capital wage equation:

$$\mathrm{Ln}(w_{if}) = X_{if}'\beta + \phi c_{if} + \varepsilon_{if}, \tag{1}$$

where $i = 1,...,N$ and denotes the number of workers per establishment ($1 \leq N \leq 25$); $f = 1,...,F$, $\mathrm{Ln}(w_{if})$ is the log of wages for individual i in workplace f, and X_{if} is a matrix of observable worker and employer characteristics that are thought to affect a worker's wage. Worker characteristics included in the model are age, gender, race, education, married, occupation, hours worked in the week, health, tenure at the workplace, training received at the workplace, whether the job was permanent and union membership. Such variables can usually be found in most types of wage analysis; see Polachek and Siebert (1993) for a review.

Wage equations using individual worker data are usually limited to including only size of workplace and industry as employer variables (see Brown and Medoff 1989; and Krueger and Summers 1988). Employer variables have been shown in other studies to influence the remuneration to workers. Agency theory predicts that there should be a difference in remuneration to workers between the case where the owners are present at the workplace, and that where ownership is separated from the control of the firm. Krueger (1991) presents a test using fast-food restaurants. The X_{if} matrix also included variables indicating the ownership and control structure of the establishment, as well as variables indicating the size of the workplace (number of employees), the industry, and union recognition. Such ownership and control variables would also affect the use of and need for communication methods at the workplace. Larger, more diversified firms require that employees communicate more effectively. Omitting these variables may lead to a larger or smaller coefficient because the variable of interest is correlated with a workplace or worker variable.

Using the large sample of workers reporting wages as a censored (grouped) variable allows more general inference on the distribution of wages between and within establishments. The pay variable was asked in terms of workers reporting their weekly or yearly pay within a specified range. For the work presented in this paper, the wage was taken as the log

weekly wage. The number of hours worked per week was conditioned as a separate regressor in the wage equation. The pay variable is grouped; an individual belongs to a wage group. Asking an individual to report pay in a grouped manner is useful for two reasons. The first is that it increases the number of responses in recording pay for each worker. The second is that it may help reduce measurement error. Provided that appropriate assumptions can be made about the underlying distribution of the variable, for example that pay across individuals is normally distributed, the grouped variable gives the same inference as asking for actual pay.

Finally, we can suppose that the error terms can be broken down into three unobserved elements: $\varepsilon_{if} = \mu_i + \lambda_f + v_{if}$. Respectively, the three elements are individual worker effects (μ_i), establishment effects (λ_f) and a random error term (v_{if}). The worker and establishment effects may be correlated with any of the variables in X, or, for the purposes of this paper, with e-mail use (c_{if}). Appendix A presents different methods of estimation that condition on the unobservable elements to varying degrees of success.

The variable of interest for this paper — different methods of communication within the workplace, and in particular e-mail use — is represented by the c_{if} variable in equation (1). Each method of communication (c_{if}) is indicated separately by a discrete variable, which takes the value of 1 if that method was used, and 0 otherwise. According to equation (1), the estimated parameter (ϕ) provides an indication of the returns from using a particular method of communication. It provides a comparison of the remuneration of workers using, say, meetings against workers who do not, conditional all the variables included in x_{if}.

Provided that all the variables that influence an individuals' wage are contained in the wage equation, estimating equation (1) will produce consistent coefficients on the elements of X_{if} and c_{if}. Complete details of the estimation procedure are given in Appendix A. Estimation of equation (1) is complicated by the fact that the dependent variable is grouped. This requires a maximum likelihood estimator and an assumption about the underlying distribution of pay within the sample. While allowing for observable characteristics, for both worker and workplace, involves standard estimation techniques, there may be unobservable characteristics of the worker or workplace that are correlated with the variable of interest, biasing the result. The basic hypothesis is that there are unobservable factors about workers (for example, other skills not associated with education) or the workplace (for example, a building that easily allows worker interaction) that may bias the returns to different types of communication. Appendix A details two different methods to attempt to condition on these unobserved factors, (a) between establishments and (b) within establishments.

If the unobserved factors are important between workplaces, this indicates that any observed returns from a communication method are more relevant at the workplace level. The establishment may rely on efficient and informative means of communicating with its work-force; similarly, the establishment's work-force is more inclined to communicate more effectively.

If the within-establishment unobserved effects are more important, then worker attributes are more important; workers are perhaps more motivated, or better able to use information and to communicate with their fellow workers, to increase their earnings.

Not all differences between workplaces are captured in unobservable factors for the set of establishments as a whole. The estimates are average effects, and in averaging across the set of establishments important differences in the observed returns to communication may be hidden. As a further examination of what may lie behind a return arising from communication and a potential correlation with unobserved worker skills, use was made of predictions from Bresnahan's (1999) organizational theory of computing, by looking at the type of workplace, and the observed wage premium/labour demand difficulties associated with different occupational classifications of workers. As a further test, e-mail use was interacted with establishments that communicate or introduce new technology to establish if it is the new technology that counts, or the attitude to communication expressed by management.

3. Results

The Basic Results

Table 3 presents the results from estimating equation (1) for the private-sector establishments. The table divides up the estimates by estimation method. What is apparent from this table is that there are large and well defined (significant at the 95 per cent level of confidence) returns to using e-mail, except when unobserved heterogeneity within establishments is conditioned out of the estimating equation (column (5)). The point estimates indicate that there is approximately a 10 per cent return from using e-mail and a 5 per cent return from attending meetings. The returns from using e-mail are similar in magnitude to those cited in Krueger (1993). There appears to be no well-defined effect from reading the company newsletter or noticeboard.

Most of the coefficients on the other worker and workplace variables are of the expected sign and magnitude, given other work with household data (Hildreth 1999). The return from age shows the usual quadratic curve; there are increasing returns from remaining at the same workplace; there are also increasing returns from training and education. Female workers earn less, as do non-white workers and those with health problems. Married workers, union members and workers in a permanent job all earn well-defined wage premiums. The workplace variables are all well determined, and most have the expected sign on the coefficient. The variables with the expected sign are size of workplace (positive), industry effects, being a franchise (negative), being part of a public limited company (PLC), and the workplace being a single-establishment firm (negative). However, the sign of the coefficient on the workplace recognition of a union is negative. It appears that the

TABLE 3
Estimates of the Returns to Using Different Methods of Communication

Dependent variable = grouped pay	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*
e-mail		0.097	0.102	0.098	0.047
		(0.007)	(0.007)	(0.034)	(0.035)
Meetings		0.053			
		(0.009)			
Noticeboard		−0.024			
		(0.011)			
Newsletter		−0.002			
		(0.008)			
Union member	0.063	0.068	0.068	−0.077	−0.113
	(0.008)	(0.008)	(0.008)	(0.039)	(0.039)
Union recognition	−0.014	−0.012	−0.013	0.066	0.097
	(0.008)	(0.008)	(0.008)	(0.080)	(0.078)
Female	−0.167	−0.163	−0.164	−0.096	−0.096
	(0.008)	(0.008)	(0.008)	(0.041)	(0.041)
O levels	0.110	0.110	0.110	0.118	0.037
	(0.010)	(0.010)	(0.010)	(0.037)	(0.040)
Degree	0.259	0.252	0.252	0.214	0.199
	(0.013)	(0.013)	(0.013)	(0.054)	(0.057)
Managers/senior administrators	0.809	0.772	0.779	0.336	0.221
	(0.017)	(0.017)	(0.017)	(0.066)	(0.066)
Professionals	0.742	0.706	0.712	0.549	0.117
	(0.018)	(0.018)	(0.018)	(0.101)	(0.130)
Associate professional/technical staff	0.618	0.583	0.586	0.239	0.216
	(0.018)	(0.018)	(0.018)	(0.070)	(0.070)
Clerical/secretarial	0.427	0.397	0.398	0.097	−0.013
	(0.015)	(0.015)	(0.015)	(0.061)	(0.064)
Craft/skilled services	0.371	0.370	0.371	0.206	0.101
	(0.017)	(0.017)	(0.017)	(0.057)	(0.057)
Personal/protective services	0.085	0.081	0.084	−0.154	−0.023
	(0.020)	(0.020)	(0.020)	(0.096)	(0.097)
Sales	0.193	0.180	0.185	0.284	0.270
	(0.017)	(0.017)	(0.016)	(0.075)	(0.084)
Operative/assembly work	0.175	0.180	0.181	0.093	0.059
	(0.016)	(0.016)	(0.016)	(0.049)	(0.047)
PLC	−0.015	−0.016	−0.016		
	(0.007)	(0.007)	(0.007)		
Log (size of workplace) (employees)	0.031	0.025	0.025		
	(0.003)	(0.003)	(0.003)		
χ^2 (6) test for age dummies	756.19	760.08	757.38	42.01	9.68
χ^2 (4) test for tenure dummies	156.46	151.51	151.92	14.68	29.90
χ^2 (4) test for training dummies	95.46	64.69	76.29	11.63	3.05
χ^2 (11) test for industry dummies	450.85	417.69	422.09		
No. of observations	13,069	13,069	13,069	12,756	8924

Notes
The number in parentheses is the standard error.
Columns (1), (2) and (3) were estimated using ordinary least squares (OLS). Column (4) was estimated as a between-establishment fixed-effects model. Column (5) was estimated as a within-establishment fixed-effects model. See Appendix A for details of the estimation procedure.
Other variables included in the OLS regressions were: age dummies, tenure dummies, training dummies, union recognition, hours per week, whether the job is permanent, race, gender, CSE, A levels, vocational qualifications, health restrictions, married, whether the workplace is part of a PLC, whether it is a single-plant firm, whether it is part of a franchise, whether it has profit-related pay, whether workers are assessed on individual performance, whether there has been ownership change, industry dummies.
Other variables included in the fixed-effects models were: age dummies, tenure dummies, training dummies, hours per week, whether the job is permanent, race, gender, CSE, A levels, vocational qualifications, health restrictions, married.

workplace recognizing a union lowers the average wage by about 1.5 per cent.[7]

Although we might expect a difference between individuals in their ability to use a computer, it is difficult to imagine, given that most people can listen in meetings, that there should be a wage premium associated with these types of communication. It is difficult to believe that there are returns from attending meetings, so there might be unobserved characteristics, of either the workplace or the workers, or both, that explain why there might be these observed wage premiums.[8] The results in the next two sub-sections discuss the effect of unobserved heterogeneity on the returns to using e-mail.

Between-Establishment Effects

Column (4) of Table 3 gives the result from estimating the wage premium for e-mail, conditional on the between-establishment effects (see Appendix A). Between-establishment fixed effects can be conditioned out of the estimating equations by transforming the variables. By averaging across workers in each individual workplace, one can then subtract the mean from the reported values to remove the unobserved establishment effect. By estimating equation (1) on the transformed variables, the estimates report a between-establishment variation in e-mail use and the effect on pay, independent of unobserved establishment and average worker effects (see Abowd and Kramarz 1999).

What is noticeable about the results in Table 3, column (4), is that the coefficient on the use of e-mail shows a positive, well defined return. There appears to be a 10 per cent return from using e-mail.[9] This indicates that it is not the workplace, or the average quality of the workers they hire, that determines the returns from communicating by e-mail. Potentially, there are still unobservable worker effects that are correlated with e-mail use that could explain the wage premium.

Within-Establishment Effects

Column (5) of Table 3 shows the within-establishment returns to e-mail (see Appendix A for details). The within-establishment fixed effects were generated by averaging across workers within pay groups, and then averaging across workers within establishments. This technique removes more variation due to workers that is not captured by the observed variables such as age, education and the variables included in the estimation of column (3). Column (5) shows that the within-establishment estimates of using e-mail are not now well defined, the coefficient is not well determined, and statistically, at a 5 per cent level of significance, the t-test on the e-mail use coefficient indicates that there is no difference from zero.[10]

The difference in the returns from communication between columns (4) and (5) can be interpreted in the following manner. The between-establishment effects in column (4) show that, despite conditioning on observed and un-

observed workplace characteristics, as well as an average of the unobserved worker characteristics, there were still significant returns to using e-mail. However, when some allowance was made for individual unobserved heterogeneity within establishments, while also including an average of the unobserved establishment effect, there was no discernable return to using e-mail. This implies that it is not the workplace *per se* that matters, but the unobserved quality of the work-force that uses e-mail. This result will be explored in a later section to the paper when examining Bresnahan's (1999) organizational computing theory.

Other results that are important to note are that the within-establishment (pay group) effects diminish the significance of age effects, occupation and training in the wage equation. The returns from education and from the within-firm tenure remain well determined. Remuneration, both within pay groups and within the firm, is mainly the result of individuals' qualifications and the time they have been employed at the particular establishment. The other result that is of some importance concerns the union wage effects of membership and of recognition. Once unobserved individual and establishment heterogeneity have been accounted for, the sign and significance of the coefficients change. The coefficients indicate that any wage premium comes from recognition rather than membership, and that membership tends to be a negative effect. These results are different from those in the literature that use household data (Hildreth 1999), but are similar to those reported in Hildreth and Pudney (1999a). Hildreth and Pudney construct a complex model to explain the union choice. A negative wage differential for union membership was the result of individual choice for non-pecuniary union benefits; a positive wage differential for union-recognized workplaces was the result of retaining better-quality workers.

Conditioning on unobserved worker and establishment effects in this manner indicates whether the average return from some factor has unobserved elements included within it. It does not indicate what factors may indicate the possible difference in workplaces or workers that gave rise to the observed premium in the first place. Providing that the variables are observed and recorded, it is possible to indicate what separates out the successful from the less successful firms, and what constitutes 'unobserved factors'.

Spurious Correlation or Wage Premium?

As a check on whether the wage premium observed between establishments in Table 3 was spurious, or was in fact a return to using e-mail as a more productive method of communication, establishment-level regressions were carried out where the dependent variable was an ordinal variable that described how well the establishment was performing, in terms of financial performance or labour productivity, against other establishments. The results of estimating how e-mail affects the performance of the workplace are given in Table 4. All variables are aggregated at the establishment level,

TABLE 4
Estimates of Workplace Performance in Using Different Methods of Communication

Dependent variable = financial performance	*Dependent variable = labour productivity*			
	(1)	*(2)*	*(3)*	*(4)*
e-mail	0.223	0.199	0.213	0.195
	(0.105)	(0.105)	(0.158)	(0.151)
Meetings	−0.032		0.020	
	(0.221)		(0.232)	
Noticeboard	0.126		−0.168	
	(0.151)		(0.234)	
Newsletter	0.256		0.049	
	(0.227)		(0.161)	
Union member	−0.232	−0.242	0.515	0.503
	(0.229)	(0.229)	(0.237)	(0.237)
Female	0.092	0.079	−0.033	−0.052
	(0.203)	(0.203)	(0.211)	(0.211)
O levels	0.160	0.203	0.129	0.203
	(0.333)	(0.331)	(0.344)	(0.343)
Degree	0.221	0.186	0.241	0.169
	(0.404)	(0.403)	(0.431)	(0.429)
Managers/senior administrators	−0.069	−0.034	−0.099	−0.070
	(0.375)	(0.374)	(0.396)	(0.393)
Professionals	−0.505	−0.467	−0.663	−0.709
	(0.447)	(0.445)	(0.472)	(0.470)
Associate professional/technical staff	0.286	0.294	−0.001	−0.099
	(0.420)	(0.418)	(0.427)	(0.424)
Clerical/secretarial	0.154	0.147	0.377	0.337
	(0.310)	(0.308)	(0.321)	(0.319)
Craft/skilled services	0.113	0.091	−0.222	−0.263
	(0.355)	(0.354)	(0.363)	(0.362)
Personal/protective services	0.156	0.127	0.352	0.296
	(0.309)	(0.326)	(0.337)	(0.335)
Sales	0.369	0.436	0.449	0.478
	(0.323)	(0.320)	(0.336)	(0.334)
Operative/assembly work	0.069	0.120	0.091	0.073
	(0.320)	(0.316)	(0.329)	(0.326)
PLC	0.084	0.104	0.076	0.106
	(0.085)	(0.084)	(0.089)	(0.088)
Log size of workplace	0.071	0.087	0.014	−0.023
	(0.036)	(0.035)	(0.036)	(0.036)
χ^2 (6) test for age dummies	9.43	8.76	11.99	11.20
χ^2 (4) test for tenure dummies	2.44	2.23	6.64	6.24
χ^2 (4) test for training dummies	2.96	2.85	8.90	10.18
χ^2 (11) test for industry dummies	14.81	14.71	12.95	12.45
No. of observations	1509	1509	1509	1509

Notes
The number in parentheses is the standard error.
Other variables included in the regressions were: establishment averages of: age dummies, tenure dummies, training dummies, union recognition, hours per week, whether the job is permanent, race, gender, CSE, A levels, vocational qualifications, health restrictions, married, whether the workplace is part of a PLC, whether it is a single-plant firm, whether it is part of a franchise, whether it has profit-related pay, whether workers are assessed on individual performance, whether there has been ownership change, industry dummies.

so that the worker variables (e.g. e-mail, female or occupational category) refer to the proportion of workers in that category within the workplace.

Table 4 shows that, even when allowing for a number of workplace variables, as well as the average characteristics of the workers who work there, there is an observed positive effect from using e-mail, both in terms of financial performance and in terms of labour productivity. Although not well determined at normal levels of significance, the coefficients on e-mail were stronger than with any other method of communication. Other methods of communication had no such productivity-enhancing effects that could be observed at the workplace level. What is also (perhaps) surprising is the lack of any role for average observable worker characteristics in determining workplace performance. While the workplace variables such as size (in terms of the number of employees) and industry were well determined, average worker characteristics such as education, age or tenure appeared to play no role.

As a further check on the possible link of unobserved effects (the workplace plus the average for the worker) to workplace performance, the estimated between-establishment effects and performance variables were correlated with each other. The correlation coefficient for the unobserved effects and the financial performance variable was positive (0.035) and significant at a 5 per cent level of significance (a standard error of 0.016). This implies a link between some part of the unobserved element and the financial performance of the workplace that is independent of the observable characteristics of the workers or the workplace. In keeping with conclusions from other papers on rent-sharing (see Hildreth and Oswald 1997), employers determine a large extent of the wage distribution.[11]

Organizational Computing and Worker Characteristics

The results in Table 3 show that unobserved worker characteristics, correlated with e-mail use, were likely to be generating the observed wage premium. While conditioning on unobserved worker variation in the manner described in Appendix A produces consistent estimates of the effects of e-mail use on pay, it does not describe what the unobserved effects are. The use of computers within an organization depends on the nature of the workplace, what it produces, how many employees there are, and what type of employee it needs. Bresnahan (1999), in setting out an organizational theory of computer use (as described in the Introduction), notes that a firm does not simply buy computers for the workforce and just put them it on the workers' desks: it needs to integrate the machines, and the users, into the company network.

Different types of worker will benefit (or not) from using e-mail within the firm. Bresnahan's theory suggests two different types of unobserved worker skill that would be correlated with e-mail use. The first is people skills, i.e. being able to deal with other people as a complement to using e-mail. The second is cognitive skills (for example, co-ordinating communication with different people), which are a substitute for e-mail use. Different occupations

across the establishment will require different mixes of the substitute or complement skills. If the substitution argument dominates, then, if the firm should have trouble hiring this type of worker, the worker could be substituted out of the workplace, and this would have negative correlation between wages and e-mail use. If the complement argument dominates, and the firm has trouble hiring workers in that particular occupation, there will be a premium to such workers and to the use of information technology.

Table 5 examines Bresnahan's (1999) theory of organizational computing as a means of examining how the unobserved ability may vary across types of worker and in different jobs and workplaces. The table is divided into four sections, reflecting employers with potentially different needs for workers with high e-mail use. The divisions are by industrial sector, production or service, and size of workplace — small (those firms below the average workplace size) and large (the average workplace size and over). According to Bresnahan's theory, the large service-sector employers would be the ones that would most need e-mail use in conjunction with workers with people skills (managers, administrators, professionals and technical workers), and the most likely to remove workers that are replaceable by e-mail (clerical and secretarial).

Table 5 was constructed in the following manner. Using equation (1), the e-mail variable was interacted with the worker's occupation title. The rest of the variables included in the regression equation were the same as those for the results shown in Table 3, column (3). The wage premium associated with e-mail now depends upon which occupation the individual is working in. There is an average effect from using e-mail, given by the coefficient on the e-mail variable, added to the effect from working in a particular occupation. The vacancy difficulty numbers were simply the mean (proportion of workplaces that reported 'yes') for that particular occupation/industry sector/size of workplace cell, correlated with the same cell e-mail use. The vacancy difficulty numbers consist of a correlation coefficient, with the number in parentheses reporting the significance of the correlation (with the null hypothesis being that there is zero correlation).

The results in Table 5 are not altogether strong in supporting Bresnahan's (1999) theory, but there is some evidence. The first result to note is that the overall wage premium for e-mail use does vary by size of workplace and by industrial sector. In both the production and service sectors, for small employers there is no significant (at usual levels) premium for e-mail use. This reflects the fact that its main effect for productive use lies with large organizations. Indeed, Table 5 shows that for large workplaces there is a well-defined premium associated with e-mail use. In terms of specifics, in large organizations in both production and service sectors, for professional workers there is a positive wage premium associated with e-mail use; also, the workplace was having difficulty hiring workers for that type of job. Workers who were able to use e-mail effectively to communicate and to inform their fellow workers were the ones receiving a wage premium. This can be contrasted with the 'clerical and secretarial' occupation group, where

TABLE 5
Estimates of Occupational Returns to Using e-Mail and Difficulties in Filling Occupational Vacancies, by Type of Workplace

Dependent variable = grouped pay	*Production sector: small employers*		*Production sector: large employers*	
	Returns coefficient	*Vacancy difficulty*	*Returns coefficient*	*Vacancy difficulty*
e-mail	−0.008		0.184	
	(0.088)		(0.073)	
Managers/senior administrators*	0.109	0.018	−0.060	0.013
	(0.096)	(0.389)	(0.082)	(0.428)
Professionals*	0.119	0.038	0.119	0.105
	(0.100)	(0.073)	(0.087)	(0.000)
Associate professional/technical staff*	0.071	0.110	−0.094	−0.016
	(0.105)	(0.000)	(0.085)	(0.335)
Clerical/secretarial*	0.066	−0.033	−0.102	0.067
	(0.095)	(0.113)	(0.079)	(0.001)
Craft/skilled services*	0.073	0.155	−0.117	−0.045
	(0.094)	(0.000)	(0.077)	(0.008)
Personal/protective services*			0.047	−0.011
			(0.275)	(0.000)
Sales*	−0.065	0.043	−0.054	−0.027
	(0.140)	(0.044)	(0.116)	(0.106)
Operative/assembly work*	0.022	0.040	−0.132	−0.136
	(0.095)	(0.061)	(0.080)	(0.000)
No. of observations	1749		2599	
	Service sector: small employers		*Service sector: large employers*	
e-mail	0.079		0.097	
	(0.059)		(0.046)	
Managers/senior administrators*	0.069	−0.020	0.042	0.070
	(0.067)	(0.144)	(0.068)	(0.000)
Professionals*	0.063	0.113	0.111	0.113
	(0.077)	(0.000)	(0.069)	(0.000)
Associate professional/technical staff*	0.038	0.076	0.006	−0.033
	(0.087)	(0.000)	(0.076)	(0.034)
Clerical/secretarial*	−0.009	0.056	−0.134	0.120
	(0.062)	(0.001)	(0.052)	(0.000)
Craft/skilled services*	−0.134	−0.086	0.033	−0.101
	(0.088)	(0.000)	(0.083)	(0.000)
Personal/protective services*	0.131	−0.077	−0.001	−0.102
	(0.096)	(0.000)	(0.088)	(0.000)
Sales*	0.016	−0.015	0.025	−0.033
	(0.064)	(0.280)	(0.056)	(0.030)
Operative/assembly work*	−0.041	−0.040	−0.084	−0.109
	(0.088)	(0.004)	(0.065)	(0.000)
No. of observations	3842		3162	

Notes
* Refers to the occupation title interacted with e-mail use.
For the Returns coefficients, the number in parentheses is the standard error. Other variables included in the regression were: age dummies, tenure dummies, training dummies, union membership, union recognition, hours per week, whether the job is permanent, race, gender, education qualifications, health restrictions, married, occupation dummies, whether the workplace is part of a PLC, whether it is a single-plant firm, whether it is part of a franchise, whether it has profit-related pay, whether workers are assessed on individual performance, whether there has been ownership change, industry dummies, size of workplace (number of employees).
'Vacancy difficulty' refers to the cell mean correlation between the occupation title and use of e-mail in that occupation in the workplace. The figures in parentheses are significance values. A value less than 0.05 indicates that the correlation does not reject the null of zero correlation between the two measures at the 95% confidence level.

workers experienced a negative wage effect associated with e-mail use, and where the employer reported no trouble in hiring workers of this type. In this instance the cognitive ability is negatively correlated with e-mail use, and some of the tasks these workers perform are instead being carried out by the new technology.

Separating Out High-Technology or High-Voice Establishments

The results from examining how unobserved ability may vary across occupations within establishments were far from conclusive. As an alternative to asking why there might be a premium associated with an ability to use e-mail within a workplace, Table 6 uses the questions on whether managers have a procedure for rewarding workers for effective communication, and whether the establishment has introduced new technology within the last five years. The variable called 'rewards' equals 1 if the management financially rewards employees who offer helpful suggestions, 0 otherwise. The variable 'new technology' equals 1 if the establishment has introduced new technology into the workplace in the last five years, or 0 otherwise.[12]

TABLE 6
Estimates of the Returns to e-mail for High-Technology and Voice-Rewarding Workplaces

	(1)	*(2)*
e-mail	0.133	0.082
	(0.009)	(0.052)
New technology	0.106	−0.004
	(0.055)	(0.027)
Financial rewards	−0.028	−0.031
	(0.012)	(0.048)
e-mail*New technology	−0.143	0.033
	(0.086)	(0.049)
e-mail*Financial rewards	0.033	0.100
	(0.016)	(0.018)
χ^2 (6) test for age dummies	1011.96	4.52
χ^2 (4) test for tenure dummies	216.74	9.60
χ^2 (4) test for training dummies	117.78	7.35
χ^2 (8) test for occupation dummies	3371.89	13.48
χ^2 (11) test for industry dummies	717.54	

Notes
The number in parentheses is the standard error.
Column (1) was estimated using ordinary least squares (OLS).
Column (2) was estimated as a within-establishment fixed-effects model; see Appendix A for details of the estimation procedure.
Other variables included in the OLS regression: age dummies, tenure dummies, training dummies, union recognition, hours per week, whether the job is permanent, race, gender, CSE, A levels, vocational qualifications, health restrictions, married, whether the workplace is part of a PLC, whether it is a single-plant firm, whether it is part of a franchise, whether it has profit-related pay, whether workers are assessed on individual performance, whether there has been ownership change, industry dummies.
Other variables included in the fixed-effects model: age dummies, tenure dummies, training dummies, hours per week, whether the job is permanent, race, gender, CSE, A levels, vocational qualifications, health restrictions, married.

To try to 'net' the effects of communication against the effects of technology from e-mail use, interaction terms were used that were the same as the method described for the results in Table 5. The results in Table 6 show an interesting pattern. First, introducing new technology has a separable effect from the use of e-mail. This implies that it is the communication itself, rather than the technological disposition of the establishment, that matters. The coefficients on both e-mail and new technology show well-defined effects in the basic cross-section equations. The second implication of the results in Table 6 is that it is not e-mail that matters at the workplace, but how managers choose to reward the introduction of useful advice by workers. The fact that e-mail has a separate (positive) effect tends to indicate that this variable is a proxy for some other unobserved characteristics of workers, as indicated in Table 3. This positive effect is correlated (to some degree) with the type of firm and occupation in which the individual works.

4. Conclusions

Using WERS to estimate the returns arising from the employment of different methods of communication has shown that any such observed returns in the data are probably a product of unobserved characteristics of the work-force at the establishment. However, some of the results on the use of e-mail suggests that there may be other factors associated with this mode of communication that are more akin to worker skills in using e-mail than to e-mail as a mode of communication *per se*. There was some evidence that a premium is associated with certain occupations being able to combine using the new technology with other unobserved skills that are a complement to e-mail use. What appears to matter within the workplace is how management chooses to reward information provision, rather than how communication is made. Further, using e-mail and introducing new technology are separable within the workplace. Overall, the results suggest that any observed returns from using e-mail are probably indicating workers' unobserved skills, for which they receive a premium against their fellow workers. E-mail may be a new voice in the workplace, but it does not realize any measurable pecuniary gain to its users unless the management chooses to structure information use in that manner.

Appendix A: Estimation with Grouped Data in Matched Employer–Employee Cross-Sections

In estimating the returns to using e-mail against other forms of communication, there are a number of problems to be overcome. One is that the dependent variable is grouped. It is not a continuous variable, as pay is often recorded as part of household surveys. Workers respond by reporting that their pay falls within a 'range' (£141–£180 per week, for example). Least

squares estimation under such conditions is biased (Stewart 1983), entailing that a least squares dummy variable approach to allow for establishment specific effects will also be biased. Stewart (1983) proposes using a maximum likelihood method with starting values being given by a 'corrected' set of least squares estimates.

The starting point is the sample. Observations on the workers are the result of a two-stage process. A stratified random sample was drawn for establishments of over 10 employees, from which a random sample of workers was drawn. A maximum of 25 employees were to be selected by the interviewer from a list of all employees provided by the management. As the sample of employees was a random draw from a stratified random draw, the sample should be approximately representative of both employers and workers in the cross-section. Hildreth and Pudney (1999a,b) discuss various issues of sampling in matching workers and employers. The panel element in WERS arises from multiple observations on workers per establishment. This allows the removal of unobservable establishment effects as given in equation (1).

The basic model (where the method of communication variable — c_{if} — is subsumed into the X vector) can be defined as:

$$w_{if} = X_{if}\beta + \varepsilon_{if}, \tag{A1}$$

where $i = 1, ..., N$; $f = 1, ..., F$, and ε_{if} can be decomposed into three elements: an individual effect (μ_i), an establishment-specific effect (λ_f) and a random error term ($v_{if} \sim N(O, \sigma_v^2)$):

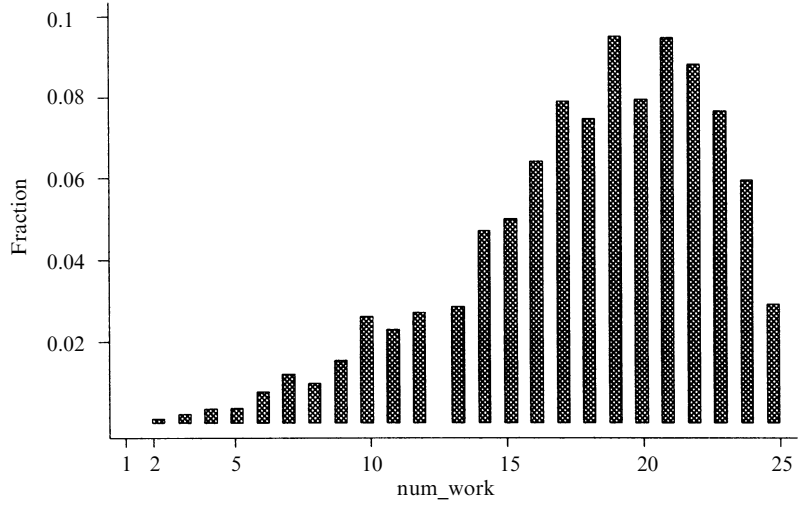
$$\varepsilon_{if} = \mu_i + \lambda_f + v_{if}.$$

From a single matched cross-section of workers and employers, the terms for μ_i and λ_f cannot be separately identified (see Abowd and Kramarz 1999 for further discussion). An aggregate firm effect can be identified because of the existence of more than one worker observation per establishment (see Figure A1). Defining the transformation matrix $(Z\mu): Z_\mu = \iota_N \otimes I_F$, where ι_N is a vector of ones of dimension N, I_F is an identity matrix of dimension $F \times F$, and $\otimes$ is the Kronecker product, the 'within' transformation matrix can be written as $\bar{I}_F = Z(Z'Z)^{-1} Z'$, and $P = J_N - \bar{I}_F$, where J_N is a matrix of ones of dimension N. The within-establishment transformation is then: $\Upsilon_{Wp} = I_{NF} - P$. However, as neither establishments nor workers are followed across time, it is possible only to identify an average workplace effect that includes an average of the worker unobserved effect. Multiplying (A1) through with Υ_{Wp} eliminates the λ_f, along with a workplace average of the μ_i. The fixed-effect that is actually removed is:

$$\xi_f = \lambda_f + \overline{\mu_f},$$

which removes the incidental parameters, but does not allow an examination of whether establishment or individual effects are potentially correlated with any of the observable worker or workplace characteristics, or in particular with the variables of interest.

FIGURE A1
Number of Workers per Establishment for the Whole Sample: WERS 1998

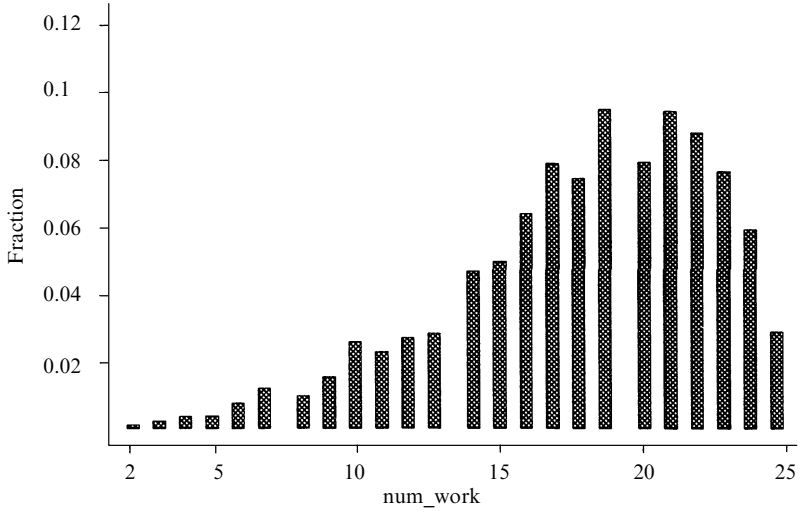


To try to obtain an indication of the importance of the individual heterogeneity within an establishment, the division of the dependent variable (pay) into groups within establishments was used to obtain an average worker effect per establishment. The 'true' dependent variable is not directly observed; instead, a grouped indicator of what pay an individual receives is observed. What is observed about pay (w_i — ignoring the conditioning on f) is that it is given in certain intervals of a real line. The real line is divided into K intervals and the real line is exhausted by these intervals such that the k^{th} interval is defined as (A_{k-1}, A_k), and the left and right parts of the distribution are defined as $A_0 = -\infty$ and $A_K = +\infty$. An indicator variable k_i $(1 \leqslant k_i \leqslant K)$ is observed for each i.

Alternatively, to try and condition on the individual fixed effect, a transformation is suggested based on the K division of the dependent variable. Identification will require that more than one person per wage group is present at the workplace. Figure A2 illustrates the difference in the sample from this restriction. The transformation is basically a within-pay-group one, across establishment. Define a matrix $Z_\lambda = \iota_N \otimes I_K \otimes I_F$, where I_K is a matrix of dimension $K \times K$. The within-pay-group transformation is then: $\Upsilon_{Wk} = I_{NF} - Q$, with $Q = J_N - \tilde{I}_{KF}$ and $\tilde{I}_{KF} = Z(Z'Z)^{-1}Z'$. If equation (A1) is now multiplied through with Υ_{Wk}, this eliminates the μ_i along with the establishment effect averaged within K: $\bar{\lambda}_K$. The fixed-effect removed has the form

$$\alpha_K = \mu_i + \bar{\lambda}_K$$

FIGURE A2
Number of Workers per Establishment for Establishments with more than Two Workers in Any Pay Group: WERS 1998



which removes an average individual effect across K that incorporates part of the averaged establishment effect. Once again, it is not possible to separate out the individual fixed effect for the worker from the establishment effect. However, the fixed effect, as defined as a within-pay-group, across-establishment effect, does allow a more refined definition of the establishment fixed effect (λ_f) if a two-way structure is assumed as part of the model.

One-way between establishment effects

The one-way model is simply the one that concentrates on the establishment effect as given by ξ_f. As part of a fixed-effects model that is analogous to the least-squares dummy variable model, the effects on wages resulting from communication structure can be estimated allowing for the establishment effect, plus the average of the workers' unobserved heterogeneity at that workplace. The model to be estimated is

$$\Upsilon_{Wp} \{w_{if} = X_{if}\beta + \varepsilon_{if}\}. \tag{A2}$$

Given the grouped nature of the dependent variable, the one-way fixed-effects model can be estimated by a basic log-likelihood function that allows for the left and right censoring of the grouped data:

$$l = \sum_{k \in G} \log \left[\Phi \left(\frac{\Upsilon_{Wp} A_{if,k} - \Upsilon_{Wp} X_{if} \beta}{\sigma_\nu} \right) - \Phi \left(\frac{\Upsilon_{Wp} A_{if,k-1} - \Upsilon_{Wp} X_{if} \beta}{\sigma_\nu} \right) \right]$$

$$+ \sum_{k \in L} \log \Phi \left(\frac{\Upsilon_{Wp} A_{if,k} - \Upsilon_{Wp} X_{if} \beta}{\sigma_\nu} \right) + \sum_{k \in R} \log \Phi \left(\frac{\Upsilon_{Wp} A_{if,k} - \Upsilon_{Wp} X_{if} \beta}{\sigma_\nu} \right),$$

provided that $\Upsilon_{Wp} A_{if,k} > \Upsilon_{Wp} A_{if,k-1}$, where Φ is the standard normal cumulative distribution function, $k \in G$ if the observation lies on the interval (A_{k-1}, A_k); $k \in L$ if the observations are left-censored; and $k \in R$ if the observations are right-censored.[13]

Assuming fixed effects implies that there are factors specific to the unit of observation that are unobserved, which the model should condition on. Assuming fixed effects implies that there are factors correlated with the observable characteristics of the worker and workplace which, if not conditioned on separately, would bias the estimated coefficients. An alternative view on the nature of unobserved heterogeneity is that the unobserved effects are random across observational units. Assuming a random effects structure implies that all factors are unconditional, or marginal, to the population of possible outcomes. In the case of technology, if the use of computers is correlated with either worker or employer characteristics, then, allowing for fixed effects, there would be an expected change in the coefficient on technology for either the worker or the workplace. If the unobserved heterogeneity is assumed random in nature, then there is the underlying assumption that the distribution of both technology and unobserved worker and employer characteristics are random across the sample.

A one-way random-effects model implies making a further assumption: that $\xi_f \sim N(0, \sigma_\xi^2)$. Random effects requires the formulation of a generalized component-weighting matrix. Following Maddala (1971), the weighting matrix for a panel data set can be written as $V = \sigma_\nu^2 I_N + \sigma_\xi^2 J_N$. The inverse of the weighting matrix is then:

$$V^{-1} = \frac{1}{\sigma_\nu^2} \left[I_N - \frac{\sigma_\xi^2}{\sigma_\nu^2 + N\sigma_\xi^2} J_N \right].$$

This is the weighting matrix used in the likelihood in the following manner:

$$l = \sum_{k \in G} \log \left[\{\Phi_k - \Phi_{k-1}\} V^{-1} \{\Phi_k - \Phi_{k-1}\} \right],$$

plus terms for left and right-censored observations.

One-way within establishment effects

The estimation for the within-establishment effect is essentially the same as for the between-establishment model. For the fixed effects, the Υ_{Wk}

transformation was used, so that (A1) is now written as

$$\Upsilon_{Wk} \{w_{if} = X_{if}\beta + \varepsilon_{if}\}. \tag{A3}$$

For the random effects model, the weighting matrix is then

$$V^{-1} = \frac{1}{\sigma_\nu^2} \left[I_N - \frac{\sigma_\alpha^2}{\sigma_\nu^2 + N\sigma_\alpha^2} J_N \right].$$

Appendix B: List of Variables by WERS Data Set

Seq98.dta (Employee Questionnaire)

serno, serial, a1, a2, a3, b2, b6a, b6b, b6c, b6d, c1, c5, d1, d2, d3, d4, d5, d6, d7, d8, d9, d10code, d11

Mq98.dta (Management Questionnaire)

serno, zallemps, asic, asingle, astatus, afranch, acontrol, aconhead, ahowlong, aownchan, dcircles, dperfor1, fvarpay1, fvarpay2, fvarpay3, fvarpay4, fmeasur1, fmeasur2, fmeasur3, fmeasur4, jnonem08, lmancha1, lmancha2, lmancha3, lmancha4, lmancha5, lmancha6, lmancha7, limpcha, ltricha1, ltricha2, ltricha3, ltricha4, ltricha5, ltricha6, lunacha, lynoch01, lynoch02, lynoch03, lynoch04, lynoch05, aphras10, dconsul1, dconsul2, dconsul3, dconsul4, dconsul5, dconsul6, khowmon1, klabscal, kestper1, kestper2, cvacdif1-cvacdif9

Final version accepted 29 November 2000.

Acknowledgements

The data are available on request to the Data Archive at the University of Essex. All programmes are available on request to the author. My thanks to John Van Reenen for providing helpful comments over a beer at the Bison Brewery on an initial draft of the paper, which helped greatly in this revision. I would also like to thank participants, in particular Willy Brown, at the British Journal of Industrial Relations WERS98 Conference at Cumberland Lodge, 20–21 September 1999, for a lively and frank discussion that led to the improvements in the paper. Thanks also to two anonymous referees whose careful reading of the paper led to a number of improvements.

Notes

1. It might be noted that Chennels and Van Reenen (1998) use the 1984 and 1990 WIRS (Workplace Industrial Relations Survey) and find that cross-section correlations show that the introduction of technology increases wages (especially for the higher skilled workers). However, when identifying the existence of technology using gender composition at the plant, there is no significant effect of technology on wages.
2. The method used by Entorf and Kramarz is to difference out the unobserved worker and firm effects. This is done by identifying through the use of 'switchers' (workers who change) between firms. If a sufficient number of workers switching between the set of firms are observed, it becomes possible to 'difference out' the unobserved elements — the same worker at two different firms, two different workers at the same firm, for example. The effects of technology are estimated both with and without the unobserved employer effects, and the difference between the two sets of estimates reveals whether unobserved worker or employer effects are correlated with the worker or firm observed variables.
3. Bresnahan (1999) describes 'people skills' as being associated with supervising and being supervised.
4. Throughout the paper, the terms 'workplace' and 'establishment' are used to mean the same entity as described in the WERS98 survey description. The principal unit of analysis for WERS98 is the establishment or workplace. A workplace is defined as comprising the activities of a single employer at a single set of premises. Examples include a single branch of a bank, a car factory or a school. This is the same definition as used by the Office for National Statistics (ONS) when surveying business units for the Annual Business Inquiry (ABI), formerly known as the Annual Census of Production. See Hildreth and Pudney (1999b).
5. A complete response was defined as a response to all the variables included in the estimation.
6. Note that the sinister index is something of an *ad hoc* construct. Equal weighting is given to each element that comprises the index. The questions used were apparently the only ones within the questionnaire that dealt with information provision and use within the workplace. As a means of examining which elements of the index were important, each component part was correlated against each communication method. Table 2 presents the results.
7. See Andrews *et al*. (1998). If union membership and union recognition dummy variables are both included in the same estimating equation, then the coefficient on the union recognition represents the coefficient on union coverage only; the union membership effect is the joint product of the coefficients on membership and recognition. In the results in Table 3 (columns (1)–(3)), the union recognition effect is slightly negative. This accords with other studies using British data (Andrews *et al*. 1998). However, both union effects are potentially biased because of the selection of different types of worker into union status and union employers.
8. The premium to meetings was not a consideration, as the paper is concerned with the use of technology for information within the workplace. The between-establishment coefficient on a wage premium for meetings is very small and not significantly different from zero (even at high levels of significance). However, as one referee pointed out, it may very well be the case that within workplaces some

workers will take part in meetings, or managers may hold meetings only with workers who come up with the best ideas. This may be true, but, as meetings have been a forum for information at the workplace for some time and do not involve a change in technology at the workplace, holding a meeting does not necessarily require the introduction of new technology, whereas communicating by e-mail does.

9. It might be noted that such a return is not too different from other estimates of using computers for British workers (Bell 1996).
10. However, it should be noted that using data in this form reduces the number of observations by a large amount (see Table 3, column (5)). The OLS results from this subset of data are not substantively different from using the whole sample.
11. Hildreth (1998) noted that the distribution of workers across profitable establishments was such that a high recorded rent-sharing parameter could explain the whole wage distribution as higher qualified workers were sorted into the lowest profit workplaces. The problem here is that the financial performance question is a relative measure (as is labour productivity). However, if we undertake the same exercise for WERS98, there is little pattern of more qualified workers being employed in poorer performing workplaces. The relative financial performance of workplaces is not explained by the observable traits of workers.
12. My thanks to an anonymous referee who pointed out that these two items are not strictly comparable. Financial rewards were asked only of managers operating 'quality circles or something similar'. It may be that workplaces that do not operate quality circles do reward employees who offer helpful suggestions. The results as presented here may be biased. There is no way to correct for this within the confines of the WERS questionnaire.
13. An alternative method that has been used before would be to condition on establishment fixed effects using the establishment specific dummy variables (Cahuc and Kramarz 1997). Although theoretically such an approach should work in this case, the fact that the dependent variable is grouped, and that so many observed characteristics are discrete, introducing establishment fixed effects into the likelihood gives it a high dimensionality. Consequently, the likelihood had trouble converging.

References

Abowd, J. M. and Kramarz, F. (1999). 'The analysis of labor markets using matched employer–employee data'. In O. Ashenfelter and D. Card (eds.), *Handbook of Labor Economics*, Vol. III. Amsterdam: North-Holland.

Andrews, M. J., Stewart, M. B., Swaffield, J. K. and Upward, R. (1998). 'The estimation of union wage differentials and the impact of methodological choices'. *Labour Economics*, 5: 449–74.

Autor, D. H., Katz, L. F. and Krueger, A. B. (1998). 'Computing inequality: have computers changed the labor market?' *Quarterly Journal of Economics*, 113: 1169–1214.

Bell, B. D. (1996). 'Skill-biased technical change and wages: evidence from a longitudinal data set'. Unpublished paper, Nuffield College, Oxford.

Bresnahan, T. F. (1999). 'Computerisation and wage dispersion: an analytical reinterpretation'. *Economic Journal*, 109: F390–F415.

Brown, C. and Medoff, J. (1989). 'The employer-size wage effect'. *Journal of Political Economy*, 97: 1027–59.

Cahuc, P. and Kramarz, F. (1997). 'Voice and loyalty as a delegation of authority: a model and a test on matched worker–firm panels'. *Journal of Labor Economics*, 15: 658–88.

Chennels, L. and Van Reenen, J. (1998). 'Establishment level earnings, technology and the growth of inequality: evidence from Britain'. *Economics of Innovation and New Technology*, 5: 139–64.

Cully, M., Woodland, S., O'Reilly, A. and Dix, G. (1999). *Britain at Work: As depicted by the 1998 Workplace Employee Relations Survey*. London: Routledge.

DiNardo, J. E. and Pischke, J-S. (1997). 'The returns to computer use revisited: have pencils changed the wage structure too?' *Quarterly Journal of Economics*, 112: 291–304.

Disney, R., Gosling, A. and Machin, S. (1995). 'British unions in decline: determinants of the 1980's fall in union recognition'. *Industrial and Labor Relations Review*, 48: 403–19.

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

Entorf, H. and Kramarz, F. (1997). 'Does unmeasured ability explain the higher wage of new technology workers?' *European Economic Review*, 41: 1489–510.

Haskel, J. (1999). 'Small firms, contracting out, computers and wage inequality: evidence from UK manufacturing'. *Economica*, 66: 1–21.

Hildreth, A. K. G. (1998). 'Rent-sharing and wages: product demand or technology driven premia?' *Economics of Innovation and New Technology*, 5: 199–226.

—— (1999). 'What has happened to the union wage differential in Britain in the 1990's?' *Oxford Bulletin of Economics and Statistics*, 61: 5–37.

—— and Oswald, A. J. (1997). 'Rent-sharing and wages: evidence from company and establishment panels'. *Journal of Labor Economics*, 15: 318–37.

—— and Pudney, S. E. (1999a). 'Employers, workers, and unions: analysis of a matched firm–worker panel with endogenous sampling and survey response'. Unpublished paper, University of California-Berkeley.

—— and —— (1999b). 'Econometric issues in the analysis of linked worker–employer cross-section surveys'. In J. C. Haltiwanger, J. Lane, J. Theeuwes and K. Troske (eds.), *The Creation and Analysis of Employer and Employee Matched Data*. Amsterdam, North-Holland.

Hirschman, A. (1970). *Exit, Voice, and Loyalty*. Cambridge, Mass.: Harvard University Press.

Krueger, A. B. (1991). 'Ownership, agency, and wages: an examination of franchising in the fast food industry', *Quarterly Journal of Economics*, 106: 75–102.

—— (1993). 'How computers have changed the wage structure: evidence from microdata, 1984–89'. *Quarterly Journal of Economics*, 108: 33–60.

—— and Summers, L. S. (1988). 'Efficiency wages and the inter-industry wage structure'. *Econometrica*, 56: 259–93.

Machin, S. and Van Reenen, J. (1998). 'Technology and changes in skill structure: evidence from seven OECD countries'. *Quarterly Journal of Economics*, 113: 1215–44.

Maddala, G. S. (1971). 'The likelihood approach to pooling cross-section and time-series data'. *Econometrica*, 39: 939–54.

Polachek, S. W. and Siebert, W. S. (1993). *The Economics of Earnings*, Cambridge: Cambridge University Press.

Stewart, M. B. (1983). 'On least squares estimation when the dependent variable is grouped'. *Review of Economic Studies*, 50: 737–54.

Van Reenen, J. (1996). 'The creation and capture of rents: wages and innovation in a panel of UK companies'. *Quarterly Journal of Economics*, 111: 195–226.