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1: Beyond unobserved heterogeneity in computer wage premiums

2: Data on computer use in Germany, 1997 – 2001

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PAPER 1: BEYOND UNOBSERVED HETEROGENEITY IN COMPUTER WAGE PREMIUMS*

Joan Musken[1] and Sybrand Schim van der Loeff[2]

Abstract

Most findings on the (non-)existence of a wage premium on computer use are biased because they are based on single-equation estimation of a wage equation. Controlling for fixed effects ignores the simultaneity problem. Through the introduction of a latent variable, "PC-feasibility", we tackle the problem of simultaneity and account for unobserved heterogeneity. Due to the simultaneous nature of wage determination and computer use, the premium for computer use becomes dependent on person and job characteristics. Imposing testable restrictions on the reduced form enables us to identify the factors that determine wages and enhance computer use. The model is estimated using German data, 1997-2001.

JELcode: J31, C31

PAPER 2: DATA ON COMPUTER USE IN GERMANY, 1997 – 2001

Joan Muysken, Sybrand Schim van der Loeff and Valeria Cheshko

Abstract

This paper describes the GSOEP data, 1997-2001, used in Muysken and Schim van der Loeff (2006). The data contain relevant information on individuals, with a focus on the computer use both at home and at work. The construction of the relevant data set for the period 1997 - 2001 is

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presented in section 2. A more detailed discussion of the data is presented in section 3 for the 1997 wave. Interesting observations are that most workers who use a computer at work started to use a computer at home simultaneously or later. Also the average number of years of employment for workers exceeds the period of the sample. Moreover there is a huge amount of inertia for computer use at work. This emphasises that fixed effects do not only control for unobserved individual characteristics, but also firm and job related characteristics. Finally, for rather homogenous groups of workers wages do not appear to vary systematically with computer use.

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*Beyond unobserved heterogeneity in computer wage premiums **

1. Introduction

The causal links between technological change, its potential skill bias and the impact on wages is a subject of extensive research – see Acemoglu (2002) for an overview. An important element of that research is to what extent the application of new technologies enhances the productivity of skilled workers using them and hence leads to a widening of wage differentials. A seminal contribution in that field is Krueger's (1993) paper on computer use and wages. He shows that the addition of a dummy for computer use in cross-sectional earnings functions, with the usual control variables, indicates that there is a significant premium for computer use at work, in the range 10 to 15 per cent. The question then is whether this represents a productivity increase stemming from computer use, or is an artifact resulting from unobserved worker or employer heterogeneity, positively correlated to both computer use and wages. Based on a very careful further exploration of his data, Krueger rejects this heterogeneity argument: "computer use at work influences earnings and not characteristics that are associated with computer use".[3]

Krueger's finding of a positive premium for computer use at work has provoked a heated debate, which was mainly of an empirical nature – cf. Kramarz (2001, Section 2) for a good survey. The cross-section result obtained by Krueger has been reproduced by many

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[3] Krueger (1993, p. 44), see also Kramarz (2001, p. 100).

authors for various other countries. A disturbing finding by DiNardo and Pischke (1997), however, was that the use of pencils earns a high premium too. Extrapolating this result to computers they conclude that (1) "computer users possess unobserved skills which might have little to do with computers but which are rewarded in the labor market", or (2) "that computers were first introduced in higher paying occupations or jobs." (p. 292).

In the first case DiNardo and Pischke posit that the observed computer premium is spurious, resulting from unobserved heterogeneity. This notion has been explored extensively by Kramarz and various co-authors by estimating wage equations from panel data applying fixed effects: Using data for France for 1987 and 1993 "all the effects of computer use that are observed in the cross-section almost completely disappear" (Kramarz, 2001, p. 104). Both Haisken-DeNew and Schmidt (1999) and Anger and Schwarze (2003) report similar findings for Germany using the GSOEP panel data.[4]

The alternative explanation put forward by DiNardo and Pischke is that computers were first introduced in higher paying occupations or jobs. This is consistent with the finding of Entorf, Gollac and Kramarz (1999) that in France computer users were better compensated than non-users even before their first use of computers. Hence "Selection of the high-quality workers is a pervasive phenomenon when firms allocate their new technologies." (p. 487). Moreover, as Kramarz (2001, p. 106) reports, Doms, Dunne and Troske (1997) find a similar result for firms in the USA: "Firms that pay high wages and use many modern techniques already paid well before adopting these techniques".

[4] We ignore here another route to control for unobserved heterogeneity introduced by Bell (1996). He includes future computer use as an explanatory variable in the wage equation for the UK, to control for unobserved abilities which might reveal themselves in computer use in future periods – he still finds a significant positive computer premium, however. Anger and Schwarze (2003) use a similar procedure, but do not find a positive premium.

Borghans and ter Weel (2003) elaborated in a simple model the notion that the causality does not run from computer use to high wages, but the other way around. They use the Skills Survey of the Employed British Work Force, 1997, to test this. From a cross-section estimation of the wage equation they find the familiar results of a wage premium of about 20 per cent. However, when taking the possible endogeneity of wages into account they find that wages turn out to be a significant variable in explaining computer use. Therefore Borghans and ter Weel conclude that "wages represent a causal impact on computer use", instead of the other way around. This conclusion is supported for Austrian data by Hofer and Riedel (2003). Finally, this finding also allows one to interpret the result of Anger and Schwarze (2003) that future computer use has a statistical significant impact on current wages as mistaken reverse causality.

This brief review of the literature shows that two important problems hamper a proper evaluation of the relationship between computer use and wages. First unobserved heterogeneity might cause a bias in the estimated impact of computers on wages. Second the causal relationship between wages and computer use might be the other way around, causing an endogeneity bias. Surprisingly, the second problem has received little attention in the literature in this field, when compared to the first problem.

Both explanations ignore the question to which extent the introduction of computers alters job skill demands. As is emphasised in Autor, Levy and Murnane (2003), computers only substitute routine cognitive and manual tasks, whereas they complement non-routine problem solving and interactive tasks. They find that relative demand for middle level employed workers doing routine tasks declines, whereas relative demand increases for high educated workers, with complementary skills.[5] Moreover, as Bresnahan, Brynjolfsson and Hitt (2002: p. 339) state: "Firms do not simply plug in computers … and achieve service quality and efficiency gains. Instead they go through a process of organizational redesign and and make substantial changes to their product and service mix." These observations lead us to model the decisions with respect to computers and wages as a simultaneous system of equations, extending the above models beyond a uni-causal framework.

We describe the GSOEP data set for Germany, 1997 – 2001, that we use in our analysis in section 2. In section 3 we apply Heckman (1978) to model the simultaneous determination of wages and computer use. Moreover, the introduction of a latent variable for "PC-feasibility" allows us to control for unobserved heterogeneity. Using a reduced form of this model, we show that for our data the hypothesis of simultaneity cannot be rejected. We also demonstrate that due to the simultaneous nature of the allocation, the premium for computer use no longer can be represented by a single parameter, but is dependent on person and job characteristics. We systematically estimate our models for each of these five years in order to verify the robustness of our results.

Section 4 shows that our structural model encompasses most models which are used in the literature. We also estimate the parameters of a structural model for our data, while testing the identifying restrictions. We show that indeed there is a strong interaction between computer use and wage determination. Apart from only using the computer at work, also "PC-feasibility" influences wages, whereas there is no evidence that wages affect the use of a PC at work. We present some concluding remarks in Section 5.

[5] Carlin and Soskice (2006, Ch. 18) argue that the resulting increased productivity also increases relative demand for low skilled workers doing non-routine service tasks.

2. The GSOEP-data for Germany, 1997-2001

2.1 The data used

The GSOEP-data set covers German households and individuals from 1984 onwards. It is an unbalanced panel with data on more than 20,000 individuals in the more recent years. Traditionally questions have been asked, amongst others, about income, personal characteristics that constitute human capital and work related variables. Hence the data set has been used intensively to estimate earnings functions in various forms; see for instance Büchel and Mertens (2000) for an overview. However, hardly any questions have been asked on the use of computers.

In 1993, 1995 and 1996 GSOEP asked whether a computer was used in the household, but only from 1997 onwards very specific questions were asked about computer use both in the household and in the work place.[6] Thus the waves since 1997 can be used to analyse the impact of computers on earnings in detail. Moreover, the data also indicate how long an individual has been using the computer.

Haisken-DeNew and Schmidt (1999) and Anger and Schwarze (2003) use these data to analyse the impact of computer use on wage differentials. Actually they combine the information on computer use in 1997 for earlier years with the data on each individual in those earlier years to construct a panel data set. They restrict themselves to full-time employed persons, living in West Germany, aged 25-60 in the years used, for which data

[6] The precise question is: Q4. Do you use a computer, either privately, on your job, in your training/education? (by computer include the personal computer (PC) or the mainframe but not a purely game machine). And since when do you use a computer?

were available in 1997 and at least one previous year. From these data they observe that females have a higher incidence of computer use. Also computer use increases with firm size and is highest for managers and office workers, around 90%, whereas it is lowest, around 20%, for production/manufacturing workers.

We use the 1997-2001 waves of these data in our analysis.[7] However, we do not limit ourselves to full-time workers in West Germany, but we also include workers in former East Germany and do not exclude part-time workers. Since a first inspection of the data revealed some outliers in the reported wages, we decided to delete those individuals who report changes in gross monthly earnings of more than 10%, unless there was a potential explanation for this large change such as change of job or position, attaining some educational degree etc. Moreover, we ignored all observations related to wage changes in excess of 25%.[8] The properties of the data are discussed in detail in Muysken, Schim van der Loeff and Cheshko (2006). The Appendix contains a list of the variables used.

2.2 Some preliminary findings

Previous findings in the literature using OLS on several specifications of a wage equation indicate significant positive effects of PC use on wages. As a check and base-case scenario we reproduce these results for our data. That is, we estimate the following wage equation:

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[7] Actually we use the GSOEP data set, which is a sub sample that covers 95% of the sample used by Haisken-DeNew and Schmidt (1999). They had access to the extended data set, which is not available for normal researchers. Moreover, we use data from 1996 and 2002 in the data-cleaning process.

[8] Roughly speaking 25 per cent of the data available each year are thus ignored, the majority of which is due to the fact that we can only use data on individuals for which we have observations in two subsequent years. In Muysken, Schim van der Loeff and Tchechko (2006) we explain in detail the process of data cleaning and analyse the properties of the data for 1997.

$$w = \delta pc + X'\beta + u \qquad (1)$$

where w represents the logarithm of the actual wage, and X is the vector of person-related and job-related factors – see the Appendix for the type of controls used – except for computer use.

To account for the latter we add a dummy, pc, which equals unity when a PC is used and is zero otherwise. The factor δ then represents the premium to computer use, which should be positive since it reflects the higher productivity of the worker when using a computer. Finally u is a random term which captures random factors and measurement errors.

The estimation results for the premium to computer use, conditional on all other characteristics, are presented in Table 1 for the five waves of the GSOEP-data. They show a remarkably good fit and the estimated values in the order of 3 – 6 % are in line with other cross-section estimation results, in particular those in Anger and Schwarze (2003), who use samples from the same population in earlier years.[9]

As pointed out in the previous section, the validity of these estimates may be questioned since there seems to be somewhat of a consensus in the literature that the finding of a positive effect of PC use on wages is due to neglected heterogeneity. However, in our view there are three problems with using fixed effects estimators to correct for unobserved heterogeneity.

The first two problems have been discussed extensively in Dolton and Makepeace (2004). First they show that for the UK the impact of computer use on wages changes over

[9] The results in Table 1 indicate that the "computer premium" seems to vary over the years, giving reason to question results using pooled cross-sections, including fixed effexts, as pointed out by Dolton and Makepeace (2004) and elaborated above.

time, which may be explained because the returns to unobserved skills have changed over time – see also Kramarz (2001) and DiNardo and Pischke (1997). A second problem is heterogeneity over individuals: returns to computer use may differ over individuals according to the complementary equipment they use. In that case "at least part of the 'return' to computing represents the increased productivity due to better capital" (Dolton and Makepeace, 2004).[10]

The third problem using fixed effect estimators is that unobserved heterogeneity will not only result from innate abilities but also cover job specific effects. Since many persons work for a prolonged period at the same firm (average tenure is over 10 years in our data), the wage differential resulting from unobserved heterogeneity is not necessarily related to innate abilities of a person, but may well be related to job characteristics which imply the use of a computer.

These comments should not be taken to deny that unobserved heterogeneity is a problem when estimating equation (1) by means of OLS. Essentially the latter assumes that, apart from random factors, productivity differentials for a situation in which some workers have identical personal and job characteristics only stem from whether a computer is used in the job or not. However, we demonstrate in Muysken, Schim van der Loeff and Cheshko (2006) that for persons with quite similar observed 'wage-relevant' characteristics, those

[10] Dolton and Makepeace (2004) do find a fall in earnings for men who stopped to use a computer later in their carreer. They explain this by these men having no longer access to highly productive capital, which is consistent with the conclusions of Autor, Levy and Murnane (2003).

who use a computer at work do not systematically earn a higher wage.[11] This observation might be explained by the heterogeneity of tasks performed within these groups, in line with the findings of Autor, Levy and Murnane (2003).[12] The notion that different tasks lead to a different use of computers implies that we should allow for the possibility that workers and computers are matched for specific reasons. Thus wages and computer use might be determined simultaneously.

3. A simultaneous model of wages and computer use

With few exceptions, see a.o. Borghans and Ter Weel (2003) and Dolton and Makepeace (2002), little attention has been paid in the literature to the – potentially serious – effects of simultaneity in the determination of wages and computer use. To repair this omission, we present a general model based on Heckman (1978) which takes this simultaneity into account. In section 4 we show that this model encompasses several other models used in the literature. In this section we estimate a reduced form of our model and show that simultaneity cannot be rejected.

[11] We distinguish gender, 5 age groups, 5 educational categories and 5 functional levels – hence 250 cells. We use all cells for which have both at least 10 persons using a computer at work and 10 workers without a computer. We find for 1997 that out of the 15 groups for which we have sufficient observations, only 5 groups show a significant difference (at 10%) in wages for computer users.

[12] Of the four age groups of males with an apprenticeship-level of education in blue collar jobs, only the second youngest age group shows a significant difference. For women, none of the three low-level white collar jobs shows a significant differene. However, out of the five middle-level white collar jobs, the three categories where women have a higher education show a significant difference. The latter observation is consistent with the findings of Autor, Levy and Murnane (2003) that in particular at this higher educational level complementarity between computers and skills may occur.

3.1 The model

We assume that workers are matched to a job in which a computer is used, based on person-related and job-related factors. As a consequence wages are not only determined by the impact of computer use, but also by other person-related and job-related factors. Some of these factors cannot be directly observed from the data available, although they are observed by the employer or worker – an example is the nature of the tasks involved. The observed use of a PC at work then provides an indication of the presence of these unobserved factors. To that aim we introduce a latent variable pc^* representing "PC-feasibility", indicating that the use of a computer in this person-job combination enhances productivity, and hence leads to a higher wage. For the latent variable holds $pc = 1$ when $pc^* > 0$ and $pc = 0$ when $pc^* \leq 0$.[13] The use of this latent variable also controls for unobserved heterogeneity.

Let the person-related and job-related factors that can be directly observed from the available data be represented by the vector X. Then wage equation (1) should be amended as follows:

$$w = \gamma_1 pc^* + \delta_1 pc + X'\beta_1 + u_1 \qquad \gamma_1 > 0 \qquad (2)$$

For simplicity we assume that PC-feasibility is also determined by variables included in the vector X. We also allow for the possibility that wages play a role in matching computers to

[13] The boundary of zero for the variable pc^* is an arbitrary choice – taking another cut-off point will not affect the analysis and the estimaton results.

workers. Also, since the observed use of a PC at work provides an indication of the presence of PC-feasibility, we include this as an additional variable. Then PC-feasibility is explained by:

$$pc^* = \gamma_2 w + \delta_2 pc + X'\beta_2 + u_2 \qquad \delta_2 \geq 0 \qquad (3)$$

$$\text{with} \quad pc = 1 \quad if \quad pc^* > 0$$
$$= 0 \quad if \quad pc^* \leq 0$$

Since pc should have a positive impact on pc^*, if any, we should find $\delta_2 \geq 0$. The simultaneous nature of the determination of wages and computer use implies that the error terms u_1 and u_2 are correlated.

Our model of equations (2) and (3) essentially is the model developed by Heckman (1978) in its most general form. Because of logical consistency, the restriction $\gamma_2\delta_1 + \delta_2 = 0$ must be imposed.[14] Imposing this restriction, but no other structural form restriction, the reduced form – or, more appropriately, the semi-reduced form – of the model composed of equations (2) and (3) can be expressed as

$$w = \delta_1 pc + X'\pi_1 + v_1 \qquad (4)$$

$$pc^* = X'\pi_2 + v_2 \qquad (5)$$

$$\text{with} \quad pc = 1 \quad if \quad pc^* > 0$$
$$= 0 \quad if \quad pc^* \leq 0$$

[14] This follows from the restriction $Prob(pc^* > 0) + Prob(pc^* \leq 0) = 1$ (Maddala, 1983, p. 118).

where π_1 and π_2 denote reduced form coefficients and v_1 and v_2 are reduced form disturbances. An interesting feature of the reduced form model is that the structural parameter δ_1 can be identified directly. The other structural parameters can only be identified by imposing further restrictions on the parameters, as we elaborate in the next section.

Heckman (1978) shows that under the assumption that v_1 and v_2 are normally distributed with a variance-covariance matrix

$$\Sigma = \begin{pmatrix} \sigma^2 & \rho\sigma \\ \rho\sigma & 1 \end{pmatrix}$$

the parameters of the model composed of equations (4) and (5) can be estimated by means of maximum likelihood.

Since wages and computer use are decided upon simultaneously the premium to computer use is no longer represented by a single parameter in the model. We find for the expected premium:

$$E(w|\, pc=1) - E(w|\, pc=0) = \delta_1 + \rho\,\sigma\, Y \qquad \rho\,\sigma\, Y > 0 \qquad (6)$$

where $\rho\,\sigma\,Y$ is a term resulting from the simultaneity bias.[15]

[15] Actually $Y = \dfrac{\phi(X'\pi_2)}{\Phi(X'\pi_2)\left[1-\Phi(X'\pi_2)\right]}$ where ϕ is the standard normal density function and Φ represents its cumulative distribution.

Table 1 *Estimation results of the computer premiums and simultaneity*[*,**]

Year (sample size)	*1997 (N=3110)*	*1998 (N=3470)*	*1999 (N=3801)*	*2000 (N=4723)*	*2001 (N=5667)*
Computer premium according to equation (1)	0.0336 (0.012)	0.0432 (0.011)	0.0616 (0.012)	0.0313 (0.012)	0.0605 (0.011)
R^2	0.810	0.779	0.764	0.746	0.768
Computer premium according to equation (6)	0.0240 [0.042]	0.0343 [0.000]	0.0564 [0.000]	0.002 [0.846]	0.0452 [0.000]
ρ	0.416 (0.074)	0.370 (0.081)	0.205 (0.11)	0.716 (0.017)	0.550 (0.022)

* Asymptotic standard errors in parentheses.
** p-values, for the test of the hypothesis that the premium is equal to zero, in square brackets

3.2 Estimation forms for the reduced form

We estimated the model for our data, using the same controls as presented in section 2. Due to the nature of the simultaneity bias, the premium to computer use according to equation (6) can only be calculated for a specific set of person-related and job-related characteristics *X*. The average computer premiums, i.e. calculated for the average set of characteristics for each year, are reported in Table 1, together with the correlation coefficient between the disturbance terms ρ, which indicates the extent to which simultaneity occurs.

To get an impression of the impact of personal and job characteristics on the premium to computer use, we present in Table 2 the premium for a married person of average age with a computer at home and education at the highest level (both actual and required for the job), working in a large firm in a professional function at a clerical occupation in the best paying sector: financial services. It is not surprising that the premium for this privileged group is much higher than the overall average of 2.4 %. Nor is it surprising, given the persistent gender gap in wages, that the wage premium is higher for males than for females. The premium also increased by 70 per cent over the period 1997 – 2001.

Table 2 *Wage premium to computer use for 3 selected groups in 1997 and 2001*

	Group characteristics*			Wage premium**	
	Sector/ Occupation	*Age/ Education*	*Function/ Firm*	*Males (1997/2001)*	*Females (1997/2001)*
(1)	Financial/ Clerical	Average/ University	Professional/ Large firm	0.214 / 0.360	0.195 / 0.336
(2)	Legal, health, Education/ Clerical	Average/ Vocational	Civil servant/ Large firm	0.106 / 0.128	0.091 / 0.112
(3)	Construction/ Foreman	20 years/ Vocational	Production/ Small firm	0.026 / 0.042	0.030 / 0.045

* Married, a computer at home and education both actual and required for the job,.
** All premiums are significantly different from zero at a 5 % level

As a contrast we also present the premia for two other groups, with different characteristics. These premiums are lower, as one might expect a priori. The premium for the two other groups has increased differently as can be seen from Table 2 – this point illustrates the different development over time of premiums for different characteristics which point was made by Dolton and Makepeace (2004). Finally, in most cases a gender gap is observed.

4. An encompassing computer allocation model

The structural model of equations (2) and (3) encompasses many models which are used in the literature analysing the impact of computer use on wages. We elaborate this below. Next we present the estimation results for the structural model and show that the models previously used in the literature have to be rejected because they ignore the simultaneity in wage determination and computer use. Finally we use our estimation results to analyse the factors which enhance computer use through "PC-feasibility".

4.1 A general model

The structural model of equations (2) and (3) encompasses many models which are used in the literature analysing the impact of computer use on wages.

When we impose $\gamma_1 = 0$, $\gamma_2 = 0$ and assume uncorrelated error terms, our model is reduced to the familiar wage equation as it has been introduced by Krueger (1993). However, the estimators of the coefficients of this equation are probably biased since, as DiNardo and Pischke (1997) state: "computer users possess unobserved skills which have little to do with computers but which are rewarded in the labor market ..." (p. 292). An obvious solution to this problem is to test for the possible endogeneity of computer use by means of instrumental variables. For that reason Dolton and Makepeace (2002) add the computer equation (3) with $\gamma_2 = 0$ to the wage equation – compare their equations (4) and (5).

Although they make no effort to interpret the variable *pc** explicitly, Dolton and Makepeace use as instrumental variables - amongst others - the answers to four questions that reveal the attitudes towards computers.[16] From that perspective its seems reasonable to interpret the variable *pc** as PC-feasibility. This is also consistent with a possible source they mention for endogeneity of PC-use in the wage equation: persons in the younger cohort would have higher levels of post-compulsory education and be more computer literate than in the older cohort.[17]

Another variant of our model results when we impose $\delta_1 = 0$. The resulting model is reminiscent of the model used by Borghans and ter Weel (2003). As we mentioned above, they emphasise the reverse causality between wages and computer use: employers will first introduce computers where wage costs can be saved most. This is also in line with DiNardo and Pischke's (1997) observation that possibly "computers were first introduced in higher paying occupations or jobs."(p. 292) To account for the possible endogeneity of wages in the computer equation (3), Borghans and ter Weel use instrumental variables. This effectively means that they add wage equation (2) with $\gamma_1 = 0$ – compare their equations (12) and (13).[18]

Given the reverse-causality interpretation of Borghans and ter Weel, and their assumption that $\delta_1 = 0$, they do not recognise any wage premium to computer use.

[16] Cf. their Table 2.
[17] The other possible source they mention is that companies are more likely to allocate computers first to workers whose productivity is most likely increased. However, these are probably workers who would have earned a higher wage in absence of computers too. Borghans and ter Weel (2003) use this as an argument to introduce wages in the compuetr equation, as we discuss below.
[18] Borghans and ter Weel (2003) use a logit approach to estimate the computer equation.

However, when their model is generalised to allow for a positive value of γ_1, i.e. $\gamma_1 > 0$, an indirect effect resulting from the impact of the latent variable still can be found.

Table 4 *Models encompassed in equations (2) and (3)*

	ρ	γ_1	γ_2	δ_1	δ_2*
The wage equation	0	0	0	> 0	0
	> 0	0	0	> 0	0
Reverse causality	> 0	0	> 0	0	0
The general model	> 0	> 0	0	?	0
			?	0	0
			> 0	< 0	> 0

* By implication, due to the restriction $\gamma_2\delta_1 + \delta_2 = 0$.

Table 4 summarises how our model of equations (2) and (3) with restrictions $\gamma_2\delta_1 + \delta_2 = 0$ and $\delta_2 \geq 0$ encompass all models in the literature we discussed above. The restrictions imposed by various specifications of the model can be tested. From the table one sees how the wage equation and reverse causality models fit the logical consistency restriction, assuming $\delta_2 = 0$, and the same holds for the generalisations when $\gamma_1 > 0$, see the first two variants of the general model. However, once we allow for $\delta_2 > 0$, logical consistency requires that we should find $\delta_1 < 0$ with $\gamma_2 > 0$ – see the last variant in the table. This would lead to results beyond the findings in the literature until now.

4.2 Estimation results

The structural model of equations (2) and (3) can be estimated by means of maximum likelihood or various two-stage methods, detailed in Maddala (1983). The structural parameter δ_1 is always identified. To identify the other structural parameters, we have to impose further restrictions on the structural model. For that purpose it is useful to distinguish between X_0, X_1 and X_2, where X_1 represents those variables which are relevant in explaining wages, but do not contribute directly to an explanation of computer feasibility, and X_2 represents the variables with an opposite function. The variables in X_0 are relevant for the explanation of both wages and computer feasibility. Thus we specify:

$$w \quad = \gamma_1 pc^* + \delta_1 pc + X'_0\beta_{11} + X'_1\beta_{12} + u_1 \qquad (7)$$

$$pc^* = \gamma_2(w - \delta_1 pc) \quad + X'_0\beta_{21} + X'_2\beta_{22} + u_2 \qquad (8)$$

When at least one exogenous variable that is excluded from equation (8) is included in equation (7), i.e. $\beta_{12} \neq 0$, the parameters of equation (8) can be identified up to a constant. This enables us to test whether $\gamma_2 \neq 0$ does hold. And when $\beta_{22} \neq 0$, the same holds for the parameters of equation (7) – β_{11} and β_{12} can even be determined exactly. Since the parameter δ_1 always is identified, we then can test indirectly whether $\delta_2 \neq 0$ does hold.[19] As

[19] The logical constraint $\gamma_2\delta_1 + \delta_2 = 0$ implies that when both $\delta_1 \neq 0$ and $\gamma_2 \neq 0$ hold, we also have $\delta_2 \neq 0$.

in the case of the reduced form the estimation procedure also allows us to test whether simultaneity is rejected or not, depending on whether ρ is significantly positive or not.

In our estimations the structural form coefficients of the attained educational level dummies *edlev3*, …, *edlev6* (*edlev1,2* has been used as reference category, see Appendix) in the PC-equation have been set equal to zero – that is the vector X_1 consists of the variables *edlev3*, …, *edlev6* – on the grounds that the relevant information on education in this equation is contained in the required (for the particular job or function) training level dummies *ausb3*, …, *ausb6* (*ausb1,2* has again been used as reference category). In the unrestricted model the wage equation contains the variable home computer use, *c_home*. As in Krueger (1993), this variable may be interpreted as a proxy for unobserved heterogeneity. Krueger, however, finds no evidence in favour of the heterogeneity argument. Also for the data at hand the support for this interpretation of the variable *c_home* is not unequivocal: the coefficient of the home computer use variable *c_home* in the wage equation is both economically and statistically insignificant except in the years 2000 and 2001.[20] Therefore the structural form coefficient of *c_home* in the wage equation has been set equal to zero (X_2 = *c_home*).

[20] In many (approximately 50%) cases workers report starting to use a computer at home in the same year or after the introduction of the computer at the workplace. Introducing a dummy variable pc_H, that takes on a value of one when an individual had a PC at home before she had this at work and zero otherwise, in the wage equation should yield a significant coefficient if indeed having a computer at home prior to having one at work controls for relevant unobserved personal characteristics. Some preliminary testing for 1997 indicated that this variable was not significantly different from zero.

Table 5 ML estimation results of the structural form equations (7) and (8)*

Year (sample size as in Table 2)	*1997*	*1998*	*1999*	*2000*	*2001*
δ_1	-0.141	-0.119	-0.0611	-0.392	-0.237
	(0.032)	(0.037)	(0.048)	(0.018)	(0.019)
γ_1	0.0574	0.0563	0.0403	0.188	0.123
	(0.013)	(0.016)	(0.018)	(0.034)	(0.014)
γ_2	2.58	2.72	1.83	-0.174	1.34
	(1.2)	(1.3)	(0.82)	(0.76)	(0.78)
δ_2**	0.364	0.324	0.112	-0.041	0.319
	(0.179)	(0.180)	(0.100)	(0.181)	(0.185)
p-value***	0.069	0.074	0.22	0.039	0.026

* Asymptotic standard errors in parentheses.
** Implied by the estimation results (delta method).
*** Likelihood ratio test of structural form restrictions.

The estimation results are presented in Table 5. The estimated values of δ_1 are in line with those found by estimation of the reduced form.[21] This is as expected in view of the fact that the restrictions imposed on the structural form are not necessary to identify δ_1. The negative estimated value of δ_1 is consistent with the general model discussed in the previous section. It is also consistent with the observation mentioned in section 2.2 that a person using a computer does not automatically earn a higher wage relative to a person with similar observed 'wage-relevant' characteristics who does not use a computer at work.

[21] This also holds for the values of ρ, not published.

The estimates for γ_1 and γ_2 are only determined up to a normalisation constant (the product of γ_1 and γ_2 is exact). Whereas γ_1 is estimated to be significantly different from zero for all years, the estimated asymptotic standard errors of γ_2 are relatively large, resulting in γ_2 being insignificantly different from zero for 2000 and 2001. Thus the notion that wages have an impact on the decision to match computer and workers must be rejected, or at least taken with a large grain of salt. The value of δ_2, implied by the estimation results, does not differ significantly from zero, except for 1997.

In summary, we find except for 1999, highly significant values for $\delta_1<0$, $\gamma_1>0$ and $\rho>0$. In terms of our generalized model this implies that both the wage equation model and the reverse causality model are rejected – cf. Table 4 above.

An important advantage of our approach is that it allows us to test the relevance of the identifying restrictions we imposed on the structural form. As the last row of Table 5 shows, the identifying restrictions are not rejected at the 5%-level of significance for the years 1997 – 1999 and not at the 1%-level of significance for the years 2000 and 2001 (with appreciably larger sample sizes, see Table 1). For ease of exposition an identical set of identifying restrictions has been chosen for all years. Some experimentation with the imposition of different restrictions reveals that restrictions that can not be rejected at high levels of significance exist for each year and that the structural parameters of interest, viz. those discussed in Table 4, with the exception of γ_2, are not sensitive to the particular set of restrictions imposed.

4.3 Beyond unobserved heterogeneity

We present in Table 6 detailed estimates of the parameters of the structural form for 1997. The estimation results for the wage equation are consistent with those found in the literature – c.f. Muysken cs. (2003). We concentrate on the estimation results for the “PC-feasibility” equation. By explicitly distinguishing the effect of variables on PC-feasibility, we avoid at least partly the impact of unobserved heterogeneity in the wage equation. The observation of the estimation results therefore allows us to a certain extent to look beyond unobserved heterogeneity.

Consistent with our interpretation of this equation, having a computer at home has a highly significant positive impact on “PC-feasibility”. Also being a woman who works part-time has a positive impact, as has being from the Eastern part of Germany. For women working part-time a possible interpretation is that allocating a computer to these women is relatively more expensive – since in many cases the computer will only be used part-time - which implies that those women who are selected to work with a computer are certainly “PC-feasible”. A similar reasoning might apply to workers in the Eastern regions, since computers might be introduced there more selectively. This is also consistent with the observation that in both cases the variable has a negative impact on wages, *ceteris paribus*.

Table 6 *ML estimation results of the structural form equations (7) and (8) for 1997*

		Equation (7)		Equation (8)	
Variable		Coefficient	Standard error	Coefficient	Standard error
Computer at work		-0,141	0,032		
Computer at home				0,966	0,109
Constant		3,294	0,108	-12,444	3,687
Hours (log)		0,778	0,017	-1,626	0,959
Female * hours		0,254	0,022	-0,892	0,379
Female		-0,123	0,017	0,113	0,199
Female * married		-0,044	0,020	0,132	0,144
Married		0,045	0,014	-0,267	0,104
Age		0,028	0,003	-0,036	0,045
Age squared		0,000	0,000	0,000	0,001
Tenure		0,007	0,001	-0,017	0,009
Ost		-0,293	0,012	0,779	0,332
Actual education	apprenticeship	0,028	0,012		
	voc. training	0,043	0,015		
	college	0,091	0,020		
	university	0,114	0,022		
Required training	on-the-job	0,051	0,018	0,207	0,155
	courses	0,070	0,024	0,614	0,219
	voc. training	0,116	0,016	0,211	0,214
	college	0,229	0,025	-0,017	0,406
Functional level (white collar)	low skilled	0,022	0,018	0,292	0,129
	med. skilled	0,058	0,022	0,676	0,181
	high skilled	0,157	0,028	0,710	0,321
	civil servant	0,018	0,028	0,811	0,197
Occupational group	sales	0,031	0,023	-0,346	0,167
	admin./manag.	0,298	0,028	-0,684	0,431
	production	0,124	0,019	-0,669	0,179
	clerical	0,094	0,021	0,644	0,219
	technical	0,176	0,021	-0,577	0,249
Firm size	20 – 200	0,109	0,012	-0,339	0,149
	200 - 2000	0,156	0,013	-0,363	0,198
	> 2000	0,196	0,014	-0,351	0,250
Branch	ind. high	0,082	0,024	0,345	0,232
	ind. low	0,022	0,024	0,129	0,194
	engineering	0,097	0,025	0,318	0,241
	construction	0,103	0,027	-0,260	0,246
	trade	-0,020	0,025	0,453	0,189
	traffic/post	-0,022	0,027	-0,027	0,208
	finance	0,135	0,032	0,108	0,306
	health/ed./legal	0,080	0,022	-0,197	0,198
	non-profit	0,061	0,023	-0,123	0,191

The impact of training required for the job does not support the notion of skill biased use of computers directly: Most levels of required training, with the exception of taking specific courses, do not have a significant impact on “PC-feasibility”. The positive impact of courses suggests that many courses are related to using a computer, which seems plausible. With regard to functional levels the effect is positive, with an increasing impact in relation to the functional level. The default functional level, blue collar, has a significant lower impact on computer feasibility. These observations are in line with the findings of Autor, Levy and Murnane (2003), except we expected unskilled white collar jobs to have an insignificant impact on computer feasibility too. The increasing impact of functional levels suggests that part of the skill-bias of computer use takes place through its impact from these levels.

Interestingly occupation plays a distinct role: Having a clerical or a service occupation has a significantly positive effect, in contrast to working in professional/technical, production or sales related occupations.

As far as firm size has an impact, only working in a small firm (the reference category) influences “PC-feasibility” positively. Here again one might expect that allocating a computer is relatively more expensive and hence workers who get a computer are selected relatively critically. There is no evidence for a branch-effect on “PC-feasibility”. This is in line with the large body of empirical evidence that the introduction of computers represented a profound technological change affecting all aspects of production (Autor, Katz, Krueger, 1998; Berman, Bound and Machin, 1998).

5. *Concluding remarks*

Since Krueger's (1993) seminal paper on computer use and wages, many authors have investigated for many countries the existence of a computer premium on wages. An important finding seems to be that when one accounts for unobserved heterogeneity, the premium is much smaller than appears at first sight. In this paper we argue that these results are biased because single wage equations are estimated. We take into account that computer use and wages are determined simultaneously, using Heckman's model of unobserved endogenous variables.

We show that this model encompasses all other models used in the literature, by imposing proper restrictions on the coefficients of the unrestricted model. Moreover, we argue the unobserved variable pc^* can be used to account for unobserved heterogeneity in an innovative way, when we interpret this as "PC-feasibility".

We estimate the model using the GSOEP-data for Germany in the years 1997 - 2001. Our OLS results indicate a significantly positive premium to computer use at work similar to those found by authors using the same kind of data, but smaller than found by Krueger for U.S. data referring to a period almost 15 years earlier. The full estimation results show that simultaneity cannot be ignored and hence single equation models are too restrictive. Our findings for the general model indicate that the structural form of this model is not rejected by the data and that "PC-feasibility", in addition to simply using a PC at work, positively influences wages but that wages in turn have no influence on "PC-feasibility".

When looking beyond unobserved heterogeneity, using the “PC-feasibility” equation from our structural model leads to several interesting observations. The obvious candidate, having a PC at home, indeed has a highly significant positive influence on “PC-feasibility”. Next there is a clear positive impact from being a part-time working women and from being married. The skill bias of computer use is not directly reflected in educational requirements, except taking specific courses, but emerges through the functional level one is working on: the higher this level is, the higher its impact on “PC-feasibility”.

Finally, while working in a small firm influences “PC-feasibility” positively, there is no evidence for a branch-effect on “PC-feasibility”. This is in line with the notion that the introduction of computers represented a profound technological change affecting all aspects of production.

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APPENDIX: The data used

Wage	
lwage:	Natural logarithm of gross monthly earnings.
Computer use	
c_work:	Computer dummy equal to one if person uses a computer at work (constructed for 1998).
c_home:	Computer dummy equal to one if person uses a computer at home (constructed for 1999).
Age	
age:	Years of age.
Gender	
gender:	Gender dummy equal to one if person is female.
Marital status	
married:	Married dummy equal to one if person is married.
Working time	
lhours:	Natural logarithm of hours worked per month.
Region	
ost:	Dummy equal to one if place of work is in the former East-Germany (1997 and 1998).
Experience	
cempl:	Years (and months) a person has worked in her current job.
Education	
edlev 1,2:	Education level dummy equal to one if person has not finished school or who have finished school but have no further education.
edlev3:	Education level dummy equal to one if person has finished school and apprenticeship.
edlev4:	Education level dummy equal to one if person has finished school and vocational training other than apprenticeship.
edlev5:	Educational level dummy equal to one if person has finished school and college.
edlev6:	Educational level dummy equal to one if person has finished school and university.
Function	
collar1:	Collar dummy equal to one if person has blue collar job.
collar2:	Collar dummy equal to one if person is industrial foreman, or does unskilled and semi-skilled white collar labour.
collar3:	Collar dummy equal to one if person is a semi-skilled professional.
collar4:	Collar dummy equal to one if person has a professional or managerial job.
collar5:	Collar dummy equal to one if person is a civil servant.
*Occupation**	
occa:	Occupational dummy equal to one if one digit isco code equal to 4 (sales).
occb:	Occ. dummy equal to one if 1digit isco-68 code equal to 2 (administrative, managerial).
occc:	Occ. dummy equal to one if 1digit isco-68 code equal to 7 (production, labor).
occd:	Occ. dummy equal to one if 1digit isco-68 code equal to 3 (clerical worker).
occe:	Occ. dummy equal to one if 1digit isco-68 code equal to 1 (professional, technical).
occf:	Occ. dummy equal to one in other cases (service sector, farming, forestry and fishing).
*In 2001 the occupation classification has been based on the 4 digit isco-88 code.	
Required training	
ausb1,2:	Firm dummy equal to one if no training or just a quick introduction in the workplace.
ausb3:	Firm dummy equal to one if on-the-job training.
ausb4:	Firm dummy equal to one if taking certain courses.
ausb5:	Firm dummy equal to one if vocational school.
ausb6:	Firm dummy equal to one if technical school or college.

*Branches of industry**	
brindl:	Branch dummy equal to one if ZUMA equals 11- 13, 40 or 41 (wood, textile, food and other light industry); NACE: 15-22, 96, 97 and 100.
brindh:	Branch dummy equal to one if ZUMA equals 5 - 8 or 42 (chemical, synthetics, ceramic, iron and steel industry); NACE: 23 – 29.
bring:	Branch dummy equal to one if ZUMA equals 9 or 10 (mechanical or elictical engineering); NACE: 30 – 36.
brconstr:	Branch dummy equal to one if ZUMA equals 14,or 15 (construction); NACE: 45.
brtrade:	Branch dummy equal to one if ZUMA equals 16 - 18 (trading, retail); NACE: 51 or 52
brtraff:	Branch dummy equal to one if ZUMA equals 19 - 21 (train, post, traffic); NACE: 60 – 64.
brfin:	Branch dummy equal to one if ZUMA equals 22 or 23 (financial institutions, insurance); NACE: 65 – 67.
brhedl:	Branch dummy equal to one if ZUMA equals 27 - 29 (legal, health service, education); NACE: 80, 85, 91 or 92.
brreg:	Branch dummy equal to one if ZUMA equals 31 - 34 (non profit, reg. authority, private househ., social security); NACE: 75 or 95.
broth:	Branch dummy equal to one in other cases (agriculture, mining, restaurants, service industry, public utilities); NACE: 1 – 14, 37 – 41, 50, 55, 70 – 74, 90, 93 or 98.
* In 2001 the industry classification has been based on the 2 digit NACE classification.	
Firm size	
fsize1:	Firm dummy equal to one if firm has less than twenty employees.
fsize2:	Firm dummy equal to one if firm has between 20 and 200 employees.
fsize3:	Firm dummy equal to one if firm has between 200 and 2000 employees.
fsize4:	Firm dummy equal to one if firm has more than 2000 employees.

Data on computer use in Germany, 1997 – 2001

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Abstract

This paper describes the GSOEP data, 1997-2001, used in Muysken and Schim van der Loeff (2006). The data contain relevant information on individuals, with a focus on the computer use both at home and at work. The construction of the relevant data set for the period 1997 - 2001 is presented in section 2. A more detailed discussion of the data is presented in section 3 for the 1997 wave. Interesting observations are that most workers who use a computer at work started to use a computer at home simultaneously or later. Also the average number of years of employment for workers exceeds the period of the sample. Moreover there is a huge amount of inertia for computer use at work. This emphasises that fixed effects do not only control for unobserved individual characteristics, but also firm and job related characteristics. Finally, for rather homogenous groups of workers wages do not appear to vary systematically with computer use.

1. The GSOEP-data

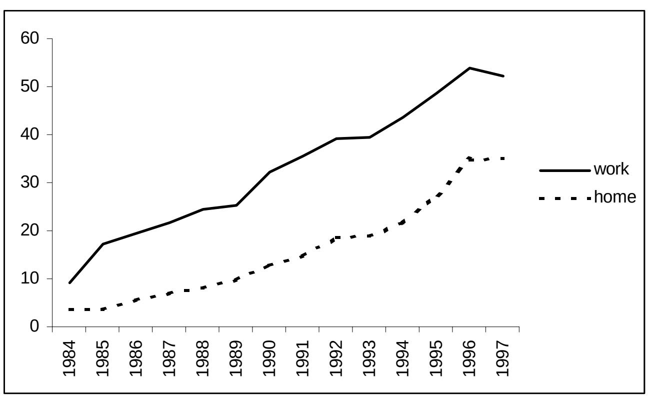
The GSOEP-data set covers German households and individuals from 1984 onwards. It is a panel data set comprising about 7,000 households and almost 14,000 individuals increasing to about 30,000 individuals for later years. Traditionally questions have been asked amongst others about income, personal characteristics that constitute human capital and work related variables. Hence the data set has been used intensively to estimate earnings functions in various forms – see for instance Büchel and Mertens (2004) for an overview. However, hardly any questions have been asked on the use of computers.

In 1993, 1996 and 1996 GSOEP asked whether a computer was used in the household, but only in 1997 very specific questions were asked about computer use both in the household and in the work place. Thus the 1997 wave can be used to analyse the impact of computers on earnings in detail. Moreover, the data also indicate how long an individual has been using the computer.[22]

Haisken-DeNew and Schmidt (1999) use these data to analyse the impact of computer use on wage differentials. Actually they combine the information on computer use in previous years with the data on each individual in those previous years to construct a panel data set. They restrict themselves to full-time employed persons, living in West Germany, aged 25 – 60 in the years used, for which data were available in 1997 and at least one previous year. They thus obtained 12482 observations on 1625 persons, which is almost 8 years on average per person.

From these data they observe that computer use has increased over time, both at work and at home. Figure 1 summarises their findings.

Figure 1 Computer use over time in West Germany, 1984 – 1997



Source: Haisken-DeNew and Schmidt (1999), Table 1.

[22] The precise question is: Q4. Do you use a computer, either privately, on your job, in your training/education? (by computer include the personal computer (PC) or the mainframe but not a purely game machine). And since when do you use a computer?

They are not surprised to find that computer use at work and at home are quite correlated: 60% of the persons who use a computer at work also use one at home, and 86% of those who use a computer at home also use one at work. Moreover, females have a higher incidence of computer use, both at home and at work. They also find that computer use at work increases with firm size and is highest for managers and office workers, around 90%, whereas it is lowest, around 20%, for production/manufacturing workers.

We focus on the same data set in our analysis, starting in 1997 – the first year in which specific questions were asked about computer use at work. However, we do not limit ourselves to full-time workers in West Germany. That is, we also include workers in East Germany and do not exclude part-time workers. Moreover, we use a sub sample that covers 95% of the sample used by Haisken-DeNew and Schmidt (1999): this is the GSOEP data set.[23] Since the questions about computer use stopped in 2002, we concentrate on the data for the period 1997 – 2001. Considerations of consistency and reliability induced us to use only data on individuals for which observations were available for at least two consecutive years. The construction of the data set, which we have used for our estimations in Muysken and Schim van der Loeff (2006), is discussed in section 2.

A more detailed discussion of the data is presented in section 3, where we limit ourselves to the 1997 wave. Some of the observations on the data are used by Muysken and Schim van der Loeff (2006). This holds amongst others for the observation that of all workers who use a computer at work only 11 per cent did use one at home before starting to use a computer at work, most workers started to use a computer at home simultaneously or later. Also the average number of years of employment for workers in their current position is in the range 6 – 9 years. Moreover there is a huge amount of inertia for computer use at work. This emphasises that fixed effects do not only control for unobserved individual charateristics, but also firm and job related characteristics. Finally, for rather homogenous groups of workers wages do not appear to vary systematically with computer use.

2. The GSOEP-paneldata for 1997 - 2001

Since questions about computer use at work were not asked after 2001, we have constructed a panel for period 1997 – 2001. For our analysis only those observations can be used for which observations on all relevant variables are available. In Table 1 details are given about the variables used by reference to their names in the GSOEP files.

Next, the observations will be passed through a 'reliability' filter. The purpose of creating and applying a filter to the data is to create a reliable database for 5 years from 1997 till 2001. Reliable is here taken to mean that extreme changes in the wage variable are explicable, and implausible values are excluded. The selection criterion was applied to the relative changes in the hourly wages for the years 1997 – 2002. This means that

[23] Haisken-DeNew and Schmidt (1999) had access to the extended data set, which is not available for non-German researchers.

observations on one-time respondents (i.e. respondents that are present for one year only) have been deleted.

The filter was constructed as follows. For every respondent in a given year, 1997 – 2001, the relative change in the hourly wage rate with respect to the previous and/or the following year was computed. If the absolute value of this change was greater than 25%, the observation was automatically excluded unless the change relative to the previous or next year - if the respondent was present in both the year before and after - was less than or equal to 10%. In that case the observation was retained. This was done to avoid deleting observations pertaining to respondents that had moved out or were moving in an apprenticeship. If the absolute value of the change (or one of the changes) in the hourly wage rate was less than or equal to 10%, the observation was retained. The choice of thresholds, albeit arbitrary, may be justified on the grounds that, given the low rate of inflation in that time span, changes in hourly wage rates exceeding those thresholds may indeed be considered extreme unless justifiable on grounds that will be detailed below..

Observations for which the absolute change in hourly wage rate was between 10 and 25 per cent were included conditionally. “Conditionally” refers to the set of factors which were considered reasonable explanations. For example a change of jobs, a change of occupation or attaining a higher grade of education were deemed an appropriate explanation for such large changes.

Table 1. Variables used from the GSOEP files in 1997-2001

	1997	1998	1999	2000	2001
Wage	np5401	op4501	pp6001	qp5601	rp5701
Computer use:					
work	np0402	rp0602[1]	pp5001	qp0705	rp0601
home	np0401	opo609	rp0502[2]	qp0703	rp0501
Gender					
Marital status	np113	op119	pp131	qp140	rp131
Working time	ntatzeit	otatzeit	ptatzeit	qtatzeit	rtatzeit
Region	np41	op89	na[3]	na[3]	na[3]
Experience	nerwzeit	oerwzeit	perwzeit	qerwzeit	rerwzeit
Education	npsbil, npbbil01-02	opsbil, opbbil01-02	ppsbil, ppbbil01-02	qpsbil, qpbbil01-02	rpsbil, rpbbil01-02
Function	np3501-5	op3501-5	pp3801-5	qp3601-5	rp4001-5
Occupation	niscoh	oiscoh	piscoh	qiscoh	is8801[4]
Required training	ausb97	ausb98	ausb99	ausb00	ausb01
Branches of industry	branch98	branch98	branch99	branch99	nace01[5]
Firm size	betr97	betr98	betr99	betr00	betr01

[1] The variable for 1998 was constructed using information from the 2001 questionnaire.
[2] The variable for 1999 was constructed using information from the 2001 questionnaire.Klopt dit?
[3] Variable not used in 1999-2001.

[4] 4 Digit ISCO-88 Occupation Code was converted to 1 Digit ISCO-68 Occupation Code.
[5] 2 Digit NACE Industry/Sector was converted to ZUMA branch of industry

Table 2 Availability of data for 1997 – 2001

	Year 1997	Year 1998	Year 1999	Year 2000	Year 2001
Gross Monthly Wage >0	6609	7027	7047	11482	10621
Information available for all variables	4619	4712	5147	5856	7693
Passing "reliability filter"	3110	3470	3801	4723	5667

The numbers of observations that result from each successive stage in the "cleaning" process are presented in Table 2. The first row records the number of respondents with positive gross monthly earnings. These numbers give a rough indication of the amount of respondents with paid employment. Since our research deals with the use of computers in the workplace, these are the respondents who are potentially relevant. The second row records the numbers of observations for which the requirement that information is available about all variables that are listed in Table 1 is available. The bottom row gives the number of observations remaining after passing the data through the "reliability filter", described above.

The selection of observations on the basis of the variable wages may lead to an unrepresentative sample. In order to ensure that the relevant characteristics of the data were not affected by the filtering procedure described above, histograms of certain key variables (e.g. educational levels) as well as ratios of them (e.g. computer use by educational level) for the sample for which information on all relevant variables was available (second row in Table 2) and the filtered sample (third row of Table 2) were compared. Using formal (χ^2-) tests, the hypothesis could not be rejected that the distributions in the two samples were the same.

3. Description GSOEP-data for 1997

3.1 General Characteristics

Table 3 presents some properties of the data – the definitions are presented in the Annex. Computer use is in the range of 40 to 50 % of working persons in age over 30 years, with a peak in the range between 40 and 50 years. It is surprisingly low below 30 years. Persons working in West Germany have a slightly higher computer use compared to East Germany, and indeed females have a higher computer use than males. Table 4 shows that persons use computers more intensively at work, the higher their education is. This holds both of education measured in years of formal schooling and using an indication of educational level. Moreover persons who have trained for their jobs use computers more intensively than people who didn't train.[24]

The above characteristics typically are personal characteristics. I.e. when the person gets another job these characteristics will remain.[25] However, there are also various characteristics that are typically attached to jobs. First there are characteristics related to the firm in which the job is held, such as firm size and sector. Table 5 shows that computer use is higher in larger firms. It is around 40 per cent in most sectors, although computer use in construction is manifestly lower (below 20 per cent) and in non-profit services is exceeds 50 per cent.

Figure 2 illustrates that the sectoral variation of computer use is not very large. The solid line shows the accumulated share in employment working with computers, when the 40 sectors are ranked according to their computer intensity. The dotted line in the figure shows the accumulated share in total employment. The divergence between the two lines indicates the sectoral variation. The figure shows that this variation is not very large. This finding is in line with the large body of empirical evidence that the introduction of computers represented a profound technological change affecting all aspects of production (Autor, Katz, Krueger, 1998; Berman, Bound and Machin, 1998).

Figure 2 Employment share over branches

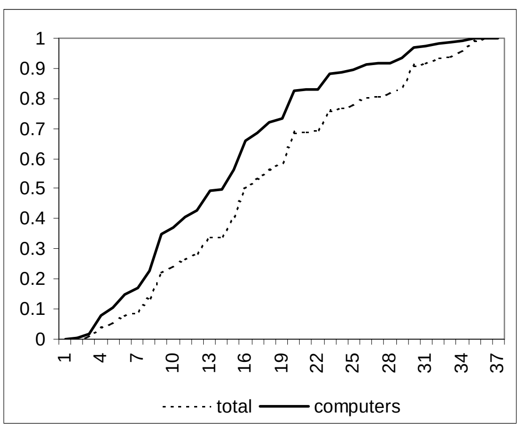


Figure 3 Employment share over occupations

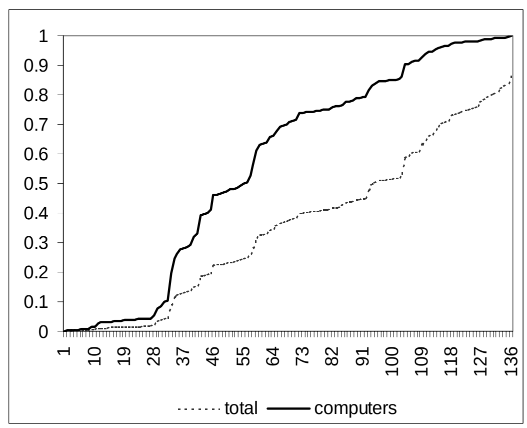


Table 3 Computer use by age, region and man-hours

Table 4 Computer use by education

[24] For 4.6 per cent of the jobs training is not necessary and for 3.9 per cent persons are currently in training.

[25] This is not necessarily true for the variables man hours and training. It is not clear whether the working time of a person is a choice which can be made for any job. However, we think it is in the majority of the cases.

	Share in total	Using a computer
Age		
<30	25.95	32.57
<40	33.87	44.76
<50	24.73	47.47
>=50	15.46	40.85
Region		
west	70.04	42.86
east	29.46	39.17
Gender		
female	39.1	46.01
male	60.9	38.88
Man hours		
<160	14.14	32.56
<180	37.42	38.22
<200	27.79	48.99
>200	20.65	44.27

Source: GSOEP 1997

	Share	Using a computer
Educational level		
2	14.17	14.85
3	45.87	37.56
4	25.06	46.06
5	4.37	72.93
6	10.52	72.19
Years of education		
<=11	39	23.86
<=12	38.57	45.18
<=15	11.81	58.5
>15	10.62	75.54
Actual training		
trained for	58.01	49.04
not trained for	33.51	37.39
not necessary	4.6	15

Source: GSOEP 1997

Figure 3, which is constructed in a similar way for over 100 occupations,[26] indicates that the variation of computer use over occupations is much larger. This brings us in the realm of typical job characteristics. Actually, it is hard to find meaningful ways of aggregating over occupations. We use here a distinction from the GSOEP-data between blue-collar, white-collar and civil service occupations, which can be subdivided in various ways. Table 2A in the Annex shows that the distinction within blue-collar workers and within civil servants is not very relevant with respect to computer use. And white-collar workers can be grouped in three categories. Table 6 presents the resulting breakdown.

Table 5 Computer use according to various firm characteristics

	Share in total employment	Share using a computer	Years current employment
Firm size			
<5	6.91	33.81	4.32
<= 20	16.94	30.87	5.1
<= 200	30.61	37.16	7.6
<= 2000	22.79	46.32	9.39
>2000	22.33	54.05	10.79
self employed	0.13	25	4.28
Sector			
primary	3.30	40.40	
industry	31.95	39.35	
construction	10.27	17.86	
market services	23.12	43.29	
non-profit services	31.12	51.66	

Source: GSOEP 1997

[26] GSOEP presents various breakdowns according to the ISCO-classification. Here we used the ISCO97-code, where over 980 categories are distinguished, although only 113 categories were actually filled.

Table 6 Computer use according to various job characteristics

		Share in total employment	Using a computer	Years current employment
Job type				
blue collar		38.54	13.82	7.97
	un/semi-skilled labour	12.13	34.42	6.58
white collar	semi-skilled professional	23.38	67.51	8.41
	professional & managerial	15.62	76.63	8.53
civil servant		6.12	68.28	13.19
Functional level				
high		17.4	63.52	9.29
medium		55.44	44.42	7.95
low		27.16	22.03	7.53
Training required				
no		3.12	9.47	5.3
introduction		8.29	9.13	6.72
fair, workplace		10.42	27.13	9.12
courses		6.71	50.49	8.76
career		52.12	44.73	8.43
higher education		14.6	75.9	8.97
Occupational group				
business		8.25	42.19	
manager		4.11	86.44	
production, labour		36.29	16.97	
office worker		20.29	80.79	
scientist		20.56	63.79	
service sector, farming, forestry, fishing		10.51	30.46	

Source: GSOEP 1997

As one might expect, Table 6 shows that computers are used more intensively in better white-collar jobs and in civil service. The same hold for jobs at higher functional levels. Finally, jobs for which career-related training or higher education is required have a computer use that is distinctly above average.

Tables 5 and 6 also reveal another interesting phenomenon: The fourth columns of both tables indicate the number of years of current employment in the jobs. It appears that many of the jobs that are characterised by a high computer use, also are jobs in which persons are working for a long time. For instance 27 per cent of the working force works in jobs of a low functional level, with an average tenure of 7.5 years and only 22 per cent uses computers. Of the 17 per cent who work in a high level job, 63 per cent uses computers and tenure is over 9 years.

3.2 Use of computers at home

One of the ways Krueger (1993) used to test the heterogeneity argument was to establish whether 'computer use at home' would yield a premium too or not. The reason was that computing at home might control for some unobserved personal characteristics: employers then might select employees on these characteristics. Following this argumentation, Haisken-

DeNew and Schmidt (1999) also reproduce this experiment in their estimations – see also Figure 1 above.

A crucial assumption in this reasoning is that workers are selected who have a computer at home when they get a computer in their jobs. Since the GSOEP-data provide information on the number of years persons use a computer at home and on their work, this assumption can easily be checked. Table 7 summarises the relevant information.

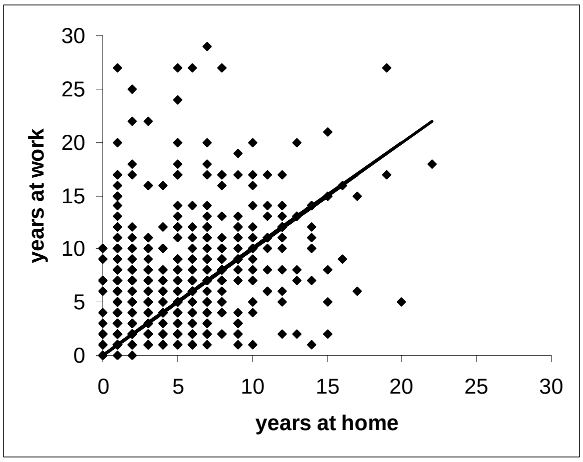
Table 7 Computer use at work and at home

	Share of total workers	Average years of use	Also computer at home/ work	Share: years at home minus years at work			Average years of current employment	Share higher current employment
				> 0	= 0	< 0		
Work	51.8	6.46	47.1	24.2	27.1	48.7	8.85	61.2
Home	28.6	4.72	85.2					

Source: GSOEP 1997

Almost 52 per cent of the workers use a computer at work, whereas only 29 uses one at home. However, of those who use a computer at home, 85 per cent also uses it at work. Of those workers who use a computer both at home and at work, only 24 per cent used a computer at home before starting to use one at work, 27 per cent started to use the computer both simultaneously at work and at home – Figure 4 summarises this point neatly. Finally of all workers who use a computer at work only 11 per cent did use one at home before starting to use a computer at work. Hence the notion that employers select workers on their use of computers at home seems not very plausible.

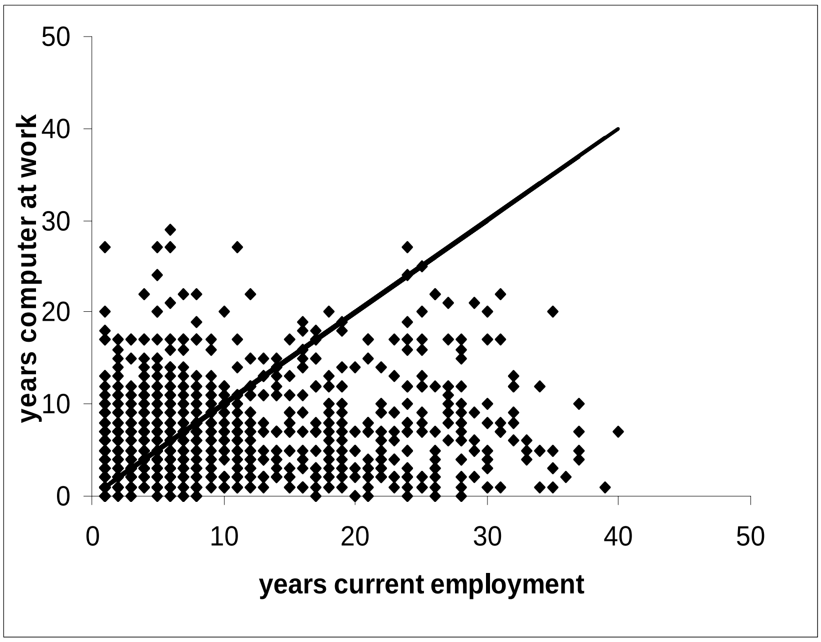
Figure 4 Years of computer use at work and at home



3.3 Fixed effects in panel data

DiNardo and Pischke (1997) stress the need to use panel data in order to control for unmeasured effects. And Kramarz and others in various studies find that using panel data for France renders the impact of computers on wages insignificant. Haisken-DeNew and Schmidt (1999) find similar results for Germany: when they use a random effect estimator, the premium on computer use at work drops significantly and with a fixed effect estimator it drops even more. A typical assumption then is that using fixed effect estimators for individual data controls for unobserved abilities and therefore eradicates the positive impact on wages from computer use at work. Some authors recognise, however, that fixed effects may also have a firm or job specific nature.

Figure 5 Years of computer use at work and work experience



The latter observation is consistent with Tables 5 – 6 who show that for many firm or job related variables the average number of years of employment in the current position is in the range 6 – 9 years. And Figure 5 indicates a huge amount of inertia for computer use at work. Hence for many individuals in the sample firm and job related characteristics are invariant over the period considered.

3.4 Wage heterogeneity and computer use

Table 8 shows for 1997 the wages for workers using a computer and not using a computer, respectively, within rather narrowly defined groups.[27] For instance, the second row indicates that in our data we find 65 young men (age1) with an apprenticeship (edlev3) working in a blue collar job (collar1). The average monthly wage of those who work with a computer of DM 3648 is slightly higher than the DM 3624 earned by those working without a computer. The t-statistic of 0.084 shows that we cannot reject the null-hypothesis that the mean wages are equal in a two-tailed test. From the Table we see that out of the 15 groups for which we have sufficient observations, only 5 groups show a significant difference in wages for computer users. This suggests that for persons with quite similar observed 'wage-relevant' characteristics, those who use a computer at work do not automatically earn a higher wage. We elaborate on this notion in Muysken and Schim van der Loeff (2006).

Table 8 *Mean wages of workers with and without computers in selected groups*

[27] We distinguish gender, 5 age groups, 5 educational categories and 5 functional levels – hence 250 cells. We only use those cells for which have both at least 10 persons using a computer at work and 10 workers without a computer. For details on the classification, see the Annex.

no. of workers	*mean wage*		*t-value*	*gender*	*age*	*education*	*collar*
	using computers	no computers					
65	3624	3648	0,084	m	1	3	1
129	3837	4472	3,336***	m	2	3	1
103	3953	4158	0,982	m	3	3	1
125	3964	4200	1,101	m	4	3	1
40	4211	4363	0,342	m	2	3	3
50	4361	4980	1,834*	m	4	4	1
27	2796	2564	-0,805	f	1	3	2
30	2800	2846	0,113	f	2	3	2
43	2279	2527	0,767	f	4	3	2
64	2879	3587	2,103*	f	4	3	3
38	2930	3827	2,251**	f	5	3	3
24	3386	3424	0,137	f	1	4	3
24	3182	3526	0,578	f	3	4	3
27	3106	4127	2,384**	f	4	4	3

Equality of mean wages rejected at 10% (*), 5% (**), 1% (***).

ANNEX: THE DATA USED

Wage	
lnwh:	Natural logarithm of hourly net wage, calculated by using the max of either actual or agreed upon hours per week worked, at most 80.
Computer use	
c_work:	Computer dummy equal to one if person uses a computer at work
c_home:	Computer dummy equal to one if person uses a computer at home
c_workt:	Number of years a person has used a computer at work
c_homet:	Number of years a person has used a computer at home
c_wt2:	Square of time worked with a computer
Age	
age1:	Age dummy equal to one if person between 25 and 34
age2:	Age dummy equal to one if person between 35 and 44
age3:	Age dummy equal to one if person between 45 and 54
age4:	Age dummy equal to one if person between 55 and 65
ageO:	Age dummy equal to one for all persons falling out of this division
Gender	
gender:	Gender dummy equal to one if person is female
Nationality	
natio:	Nationality dummy equal to one if person not born in Germany
Working time	
mhours:	Number of hours worked per month by a person
Region	
ost:	Dummy equal to one if person is from the former east of Germany
Experience	
totexp:	Total working experience of a person in years
cempl:	Years (and months) a person has worked in her current job
prevexp:	Years of experience the person had previous to the current job
texpsq:	Total experience squared
Education	
edyears:	The total amount of years of schooling received by a person
edlev 1,2:	Education level dummy equal to one if person has not finished school or who have finished school but have no further education
edlev3:	Education level dummy equal to one if person has finished school and apprenticeship
edlev4:	Education level dummy equal to one if person has finished school and vocational training other than apprenticeship
edlev5:	Educational level dummy equal to one if person has finished school and college
edlev6:	Educational level dummy equal to one if person has finished school and university
Function	
wcl:	Collar dummy equal to one if person has white collar job (is collar 2,3 and 4 below)
collar1:	Collar dummy equal to one if person has blue collar job
collar2:	Collar dummy equal to one if person is industrial foreman, or does unskilled and semi-skilled white collar labour
collar3:	Collar dummy equal to one if person is a semi-skilled professional
collar4:	Collar dummy equal to one if person has a professional or managerial job
collar5:	Collar dummy equal to one if person is a civil servant
Occupation	
occa:	Occupational dummy equal to one if one digit isco code equal to 4 (=business)
occb:	Occ. dummy equal to one if one digit isco code equal to 2 (=Manager)
occc:	Occ. dummy equal to one if one digit isco code equal to 7 (=production, labor)
occd:	Occ. dummy equal to one if one digit isco code equal to 3 (=office worker)
occe:	Occ. dummy equal to one if one digit isco code equal to 1 (=scientist)
occO:	Occ. dummy equal to one in other cases (service sector, farming, forestry and fishing)
Required training	
Ausb;2:	Firm dummy equal to one if no training or just a quick introduction in the workplace
ausb3:	Firm dummy equal to one if fairly lengthy training at the workplace
ausb4:	Firm dummy equal to one if taking certain courses
ausb5:	Firm dummy equal to one if carreer training

ausb6:	Firm dummy equal to one if higher education
Branches of industry	
bra:	Branch dummy equal to one if ZUMA equal to 3 (=energy and water)
brb:	Branch dummy equal to one if ZUMA equal to 5 (=chemical industry)
brc:	Branch dummy equal to one if ZUMA equal to 6 (=synthetic industry)
brd:	Branch dummy equal to one if ZUMA equal to 7, 4 (=mining, stone,earth)
bre:	Branch dummy equal to one if ZUMA equal to 8, 9 (=iron, steal, mechan.)
brf:	Branch dummy equal to one if ZUMA equal to 11 (=wood, paper, print)
brg:	Branch dummy equal to one if ZUMA equal to 12 (=textile clothing)
brh:	Branch dummy equal to one if ZUMA equal to 13 (=food industry)
bri:	Branch dummy equal to one if ZUMA equal to 14, 15 (=construction)
brj:	Branch dummy equal to one if ZUMA equal to 16, 17, 18 (=trading, retail)
brk:	Branch dummy equal to one if ZUMA equal to 19, 20, 21 (=train, post, traffic)
brl:	Branch dummy equal to one if ZUMA equal to 22 (=financial institutes)
brm:	Branch dummy equal to one if ZUMA equal to 24, 25, 27, 28, 29, 30 (=legal, health service, education)
brn:	Branch dummy equal to one if ZUMA equal to 31, 33 (=non profit, reg. authority)
brO:	Branch dummy equal to one in other cases (social security, trash removal, private household, agriculture, fishing)
Firm size	
difsize1:	Firm dummy equal to one if firm has less than twenty employees
difsize2:	Firm dummy equal to one if firm has between 20 and 200 employees
difsize3:	Firm dummy equal to one if firm has between 200 and 2000 employees
difsizeO:	Firm dummy equal to one if firm has more than 2000 employees

Table 1A Branches of industry

Branch		no_comp	yes_comp	total	branch share	share_comp
1	AGRIC.,FORESTRY	35	10	45	0.015	0.22
3	ENERGYANDWATER	15	27	42	0.014	0.64
4	MINING	9	3	12	0.004	0.25
	PRIM&SEC	*59*	*40*	*99*	*0.033*	*0.40*
5	CHEMICAL INDUST	35	40	75	0.025	0.53
6	SYNTHETICINDUST6	18	7	25	0.008	0.28
7	CLAYSTONEEARTH 7	18	5	23	0.008	0.22
8	IRONSTEELINDUST8	127	62	189	0.063	0.33
9	MECHANICAL ENG.9	112	84	196	0.065	0.43
10	ELECTRICAL ENG10	54	75	129	0.043	0.58
11	WOODPAPERPRINT11	64	24	88	0.029	0.27
12	TEXTILECLOTHNG12	24	7	31	0.010	0.23
13	FOOD INDUSTRY 13	59	18	77	0.026	0.23
40	OTHERINDUSTRY 40	35	21	56	0.019	0.38
41	OTHLIGHTINDUST41	8	4	12	0.004	0.33
42	OTHHEAVYINDUST42	27	30	57	0.019	0.53
	INDUSTRY	*581*	*377*	*958*	*0.320*	*0.39*
14	CONSTRUCTION 14	157	46	203	0.068	0.23
15	CONSTRUCTRELAT15	96	9	105	0.035	0.09
	CONSTR	*253*	*55*	*308*	*0.103*	*0.18*
16	WHOLESALE 16	23	29	52	0.017	0.56
17	TRADING AGENTS17	0	2	2	0.001	1.00
18	RETAIL 18	195	111	306	0.102	0.36
19	TRAIN SYSTEM 19	12	4	16	0.005	0.25
20	POSTAL SYSTEM 20	19	9	28	0.009	0.32
21	OTH.TRAFFICSYS21	62	40	102	0.034	0.39
22	FINANCIALINSTI	18	76	94	0.031	0.81
23	INSURANCE CO. 23	4	21	25	0.008	0.84
24	RESTAURANTINNS	43	7	50	0.017	0.14
25	SERVICEINDUSTR25	17	1	18	0.006	0.06
	SERVICE	*393*	*300*	*693*	*0.231*	*0.43*
26	TRASH REMOVAL 26	11	6	17	0.006	0.35
27	EDU,SCI,SPORTS27	83	83	166	0.055	0.50
28	HEALTH SERVICE28	165	121	286	0.095	0.42
29	LEGAL SERVICE 29	21	56	77	0.026	0.73
31	NONPROFITGROUP31	48	34	82	0.027	0.41
32	PRIVATHOUSEHLD32	4	0	4	0.001	0.00
33	REGIONLAUTHRTY33	111	152	263	0.088	0.58
34	SOCIALSECURITY34	8	30	38	0.013	0.79
	NP SERV	*451*	*482*	*933*	*0.311*	*0.52*

Source: GSOEP 1997

Table 2A Computer use according to various job types

		Share in total	Using a computer	Years current employment
Job type				
blue collar		38.54	13.82	7.97
white collar	un/semi-skilled labour	12.13	34.42	6.58
	semi-skilled professional	23.38	67.51	8.41
	professional & managerial	15.62	76.63	8.53
civil servant		6.12	68.28	13.19
Blue collar				
unskilled		2.6	3.8	5.4
semi-skilled		11.58	11.08	8.45
skilled		20.39	14.52	7.64
foreman		2.56	17.95	10.29
master craftsman		1.41	37.21	9.44
White collar				
industrial foreman		1.09	51.52	11.5
unskilled		3.65	18.02	5.19
semi-skilled labour		7.4	40	6.54
semi-skilled professional		23.38	67.51	8.41
professional		14.24	75.98	8.52
managerial		1.38	83.33	8.56
Civil Servant				
lower		0.3	11.11	8.71
middle		2.07	66.67	11.51
upper		2.43	77.03	14.06
executive		1.32	67.5	15.21

Source: GSOEP 1997

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