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THE RETURNS TO COMPUTER USE REVISITED: HAVE PENCILS CHANGED THE WAGE STRUCTURE TOO?*

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Are the large measured wage differentials for on-the-job computer use a true return to computer skills, or do they just reflect that higher wage workers use computers on their jobs? We examine this issue with three large cross-sectional surveys from Germany. First, we confirm that the estimated wage differential associated with computer use in Germany is very similar to the U. S. differential. Second, we also measure large differentials for on-the-job use of calculators, telephones, pens or pencils, or for those who work while sitting down. We argue that these findings cast some doubt on the literal interpretation of the computer use wage differential as reflecting true returns to computer use or skill.

I. INTRODUCTION

In a careful and influential study Krueger [1993] finds that workers who use computers on the job earn 15 to 20 percent more than nonusers after controlling for standard worker attributes. Many have interpreted Krueger's findings as direct evidence favorable to the hypothesis that changes in technology have been responsible for much of the dramatic changes in the wage structure observed in the United States in the last 25 years. Although Krueger [1993] addresses the issue of whether computers have changed the wage structure, the bulk of Krueger's focus is on estimation of the magnitude of the computer wage differential for a typical worker. Using a variety of approaches, he attempts to ascertain whether the wage differentials he estimates primarily represent a "causal" relationship between computers and wages or whether the observed differentials are largely a reflection of unobserved worker heterogeneity: workers with other unobserved characteristics that lead to higher wages are more likely to use computers on the job. Since Krueger relies on cross-sectional data, he cannot and does not control for individual fixed effects. Absent an appropriate instrumental variable for com-

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puter use that would allow a direct estimation of an average "treatment effect," Krueger instead uses a variety of indirect methods. In general, he finds evidence consistent with the view that the measured differential primarily reflects a causal effect of on-the-job computer use.

In this paper we replicate Krueger's analysis using data on German workers. Our estimates of the computer wage premium are similar to those found by Krueger. However, because our data contain much more detailed information on the tools used by workers on their jobs, we are able to apply the same techniques to estimate the wage differentials associated with the use of a calculator, a telephone, writing materials like a pen or pencil, or sitting on the job. When we do so, we find that the measured wage differentials associated with these "white-collar" tools are almost as large as those measured for computer use. We also find a wage penalty associated with the use of "blue-collar" tools. Since we do not believe that workers reap substantial rewards for using pencils or chairs on their job, we are somewhat more skeptical about whether an exercise like this is likely to recover the causal effect of computer use on wages either. Instead, the results seem to suggest that computer users possess unobserved skills which might have little to do with computers but which are rewarded in the labor market, or that computers were first introduced in higher paying occupations or jobs.

The remainder of the paper is organized as follows. The next section describes the German data sets we use. Section III presents the measured wage differentials associated with the use of tools in the United States and in Germany. The final section discusses the interpretation of these results.

II. The Data

Our German data come from three cross sections of the West German *Qualification and Career Survey,* conducted in 1979, in 1985–1986, and in 1991–1992 by the Federal Institute for Vocational Training (BIBB) and the Institute for Labor Market Research (IAB). The surveys contain standard demographic and labor market variables but are also particularly rich in detail about workers' jobs, job attributes, and the tools used in these jobs. The sampling frame for the survey is the German employed population aged 16 to 65, and each survey has slightly less than

30,000 respondents. We use the largest sample possible, only deleting observations that do not have information on the variables we analyze. The questions in the three surveys are similar but not exactly comparable. We report below more details on the variables we use.

The questions on computer use differ slightly between the 1979 survey and the later waves. For the 1979 survey we combine affirmative answers to two questions as computer users. The first asked about the use of "computers, terminals, or monitors;" the second inquired about word processors. In the later surveys there are six categories that we combine: computers on shop floors, office computers, PCs, terminals, word processors, and CAD systems. Other questions inquired about the use of computer-controlled machinery, but this seems to be different from the concept captured in the questions in the U. S. Current Population Survey (CPS) used by Krueger [1993].

The top panel in Table I summarizes the probability of using a computer at work for different categories of workers and reproduces a similar tabulation from Autor, Katz, and Krueger [1996], who have updated the results of Krueger [1993] until 1993. Computer use in the mid-1980s is lower in Germany than in the United States, but by 1991 the fraction of workers using computers on the job in Germany is very similar to the U. S. utilization rate in 1989. Computer use has increased strongly during this period in both countries. Likewise, the patterns of use among various labor market groups are very similar. In both countries computers are used predominantly by the more highly educated, by the age group 25–39, by white-collar workers, and by full-time employees.

III. The Wage Differentials for Workplace Tools in the United States and in Germany

To assess the wage differential associated with using computers, we run a number of standard wage regressions. Our dependent variable is the log of gross average hourly earnings. This variable is constructed from monthly earnings and usual weekly hours.[1]

1. The earnings variable in the survey is obtained not as a continuous number but in bracketed form. There are 13 brackets for the 1979 survey, 21 in 1985–1986, and 15 in 1991–1992. We assigned bracket midpoints to each group. The

TABLE I
PERCENT OF WORKERS IN VARIOUS CATEGORIES WHO USE DIFFERENT TOOLS ON THEIR JOB

Group	U. S. 1984	U. S. 1989	U. S. 1993	Germany 1979	Germany 1985–1986	Germany 1991–1992
	Percentage that are computer users					
All workers	25.1	37.4	46.6	8.5	18.5	35.3
Men	21.6	32.2	41.1	7.9	18.5	36.4
Women	29.6	43.8	53.2	9.7	18.5	33.5
Less than high school	5.1	7.7	10.4	3.2	4.3	9.9
High school	19.2	28.4	34.6	8.5	18.3	32.7
Some college	30.6	45.0	53.1	8.5	24.8	48.4
College	42.4	58.8	70.2	13.4	30.5	61.6
Age 18–24	20.5	29.6	34.3	10.1	13.8	27.8
Age 25–39	29.6	41.4	49.8	9.6	21.6	39.9
Age 40–54	23.9	38.9	50.0	6.6	17.2	35.9
Age 55–64	17.7	27.0	37.3	5.9	13.5	23.7
Blue-collar	7.1	11.2	56.6	1.2	3.5	10.7
White-collar	39.7	56.6	67.6	12.8	28.9	50.2
Part-time	14.8	24.4	29.3	6.4	14.7	26.5
Full-time	29.3	42.3	51.0	8.7	19.1	37.0
	Percentage of all workers who use a specific tool					
Computer	25.1	37.4	46.6	8.5	18.5	35.3
Calculator				19.6	35.7	44.2
Telephone				41.8	43.7	58.4
Pen/pencil				54.9	53.4	65.6
Work while sitting[a]				30.8	19.3	—
Hand tool (e.g., hammer)				29.4	32.9	30.5
Number of obs.	61,704	62,748	59,852	19,427	22,353	20,042

a. Variable definition differs in 1979 and 1985–1986. In 1979 it refers to "Never or rarely standing," and in 1985–1986 it refers to "Often or almost always sitting."

Columns 1 to 3 are from Table 3 in Autor, Katz, and Krueger [1996] and come from the October *Current Population Survey*. German data are from the *Qualification and Career Survey*.

resulting approximation should be rather good because of the large number of brackets. Adopting a similar specification, we find that this earnings variable yields the same return to schooling in 1985–1986 as reported by Krueger and Pischke [1995] with a continuous earnings variable for 1988. Years of education are imputed from information on schools attended and degrees obtained following Krueger and Pischke [1995]. When we bracket the earnings variable in the October 1984 CPS to be comparable with our 1979 data, in a regression similar to Krueger's we find a computer coefficient of 0.1697 using the original wage variable, and 0.1701 using the bracketed variable. Standard errors are about 3 percent larger with the bracketed variable.

TABLE II
OLS REGRESSIONS FOR THE EFFECT OF COMPUTER USE ON PAY
DEPENDENT VARIABLE: LOG HOURLY WAGE
(STANDARD ERRORS IN PARENTHESES)

Independent variable	U. S. 1984	U. S. 1989	U. S. 1993	Germany 1979	Germany 1985–1986	Germany 1991–1992
Computer	0.171	0.188	0.204	0.112	0.157	0.171
	(0.008)	(0.008)	(0.008)	(0.010)	(0.007)	(0.006)
Years of	0.068	0.075	0.081	0.073	0.063	0.072
schooling	(0.001)	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)
Experience	0.028	0.028	0.026	0.030	0.035	0.030
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Experience^2/	−0.043	−0.043	−0.041	−0.052	−0.058	−0.046
100	(0.002)	(0.002)	(0.003)	(0.002)	(0.002)	(0.002)
R^2	0.444	0.448	0.424	0.267	0.280	0.336
Number of obs.	13,335	13,379	13,305	19,427	22,353	20,042

Columns 1 to 3 are from Table 4 in Autor, Katz, and Krueger [1996]. Data for columns 1 to 3 are from the October *Current Population Survey;* data for columns 4 to 6 are from the *Qualification and Career Survey.* All models also include an intercept, a dummy for part-time, large city/SMSA status, female, married, female*married. Regressions for the United States in columns 1 to 3 also include dummies for black, other race, veteran status, union membership, and three regions. Regressions for Germany in columns 4 to 6 also include a dummy for civil servants (*Beamter*).

The raw log wage differential for computer use in Germany is 0.139 in 1979, 0.239 in 1985–1986, and 0.288 in 1991–1992. This is somewhat lower than the 0.276 differential for the United States in 1984 and 0.325 in 1989 reported by Krueger [1993]. In both countries the inclusion of controls such as education, experience, gender, and others lowers the computer wage differential. In Table II we report estimates from OLS wage regressions that include a computer dummy and other covariates. The first three columns are reproduced from Autor, Katz, and Krueger [1996]. Our estimates from the German data, reported in the last three columns of Table II, are 0.112 in 1979, 0.157 in 1985–1986, and 0.171 in 1991–1992. These are comparable to the U. S. estimates, although the German estimates are slightly lower. Furthermore, in both countries the wage differential associated with computer use has increased over time.

Both the basic patterns of on-the-job computer use and the estimated computer wage differentials are very similar in the United States and in Germany. This similarity is noteworthy given that the German labor market is more regulated, pay setting more centralized, and the wage structure more compressed than in the United States (see, e.g., Krueger and Pischke [1995]).

Our analysis thus far suggests that the labor markets of the two countries are sufficiently similar that analysis of the German data will be informative about the interpretation of the wage differentials in U. S. data. Using our considerably more detailed German data, we now analyze a number of tools that might invite a different interpretation of the associated wage differential.

The fraction of workers who mention that they utilize the tools we consider are displayed in the bottom panel in Table I. We have discussed the fact that computer use has grown substantially during the 1980s. Desk or hand calculators (the 1979 data also include cash registers in this category) are used more heavily, and their usage has also increased substantially during this period. Telephones are used by about half the workforce, although unlike computers or calculators their use has changed little during this period. Approximately 60 percent of workers use a pen, pencil, or other writing material on their job. We also consider a variable that indicates whether the respondent works predominantly while sitting. The 1985–1986 survey had a direct question on how often respondents sit at their job, allowing five possible answers: basically never, rarely, occasionally, often, almost always. We classified those responding “often” or “almost always” as sitting. In 1979 the only similar question asked how often respondents stand, allowing the same five responses. We classified those standing “never” or “rarely” as sitting. There is no such variable in the 1991–1992 survey. The fractions sitting differ between the two years; this is likely to be due to the differences in our variable definitions.

To compare workers associated with “office” work or more supervisory roles to blue-collar workers, we also consider the usage of manual hand tools such as hammers, screwdrivers, paintbrushes, hand-operated drills, etc. About 30 percent of workers use such tools; this has changed little over the period we consider.

In Table III we report the wage differentials associated with these various tools using regressions similar to those reported in Table II. In the first panel we report results from separate regressions for each tool we consider. We display only the coefficients on the tools. We find differentials of 9 to 14 percent associated with the white-collar tools and sitting on the job. This is to be compared with an 11 to 17 percent differential for computer use. Thus, the estimated differentials for other tools are of the same magnitude but slightly lower than the computer effect, especially for the later years. By contrast, when we run similar regressions for blue-collar hand tools, we find that the use of such tools is associated with a 9 to 11 percent *lower* wage.

One obvious objection to these regressions might be that the use of a telephone or sitting on a chair is associated with particular occupations so that these tools simply proxy for the occupation wage structure. To control for the part of the wage differential attributable to occupational wage differentials, the last four columns of Table III present results from the same regressions that now include a very detailed set of occupation dummies; the number of occupation dummies ranges from 501 in 1979 to 1071 in 1991–1992.

The inclusion of detailed occupation dummy variables lowers the returns to most tools to 30 to 50 percent of their original value. Thus, a large fraction of the original differentials are indeed associated with occupations. Nevertheless, differences in wages on the order of 4 to 7 percent remain for the users of the various office tools even within narrowly defined occupations. This again mirrors the within-occupation estimates reported by Krueger [1993] for the United States.

It is also possible that the use of pencils, calculators, etc. might simply be proxying for the use of a computer. To rule out that possibility, we include all five office tool dummy variables together in the regression simultaneously. The results are reported in the bottom panel of Table III (the 1991–1992 results do not include sitting). While the differential associated with each falls, they all stay individually significant. The computer differential with 7 to 13 percent remains among the largest, but the differentials for telephones and jobs that involve sitting also remain on the order of 5 to 7 percent. Thus, while there is a good deal of correlation between the use of these tools, the use of telephones or calculators did not purely proxy for computer use. The results are again qualitatively similar when we include occupations. One result worthwhile noting is that the computer coefficient increases strongly over time when all tools are entered in the regression together while some of the other coefficients tend to fall over time. This might indicate that the role of computers in the workplace might be changing over time.

One way to address the possibility of unobserved heterogeneity in these regressions is to include other controls for ability. Krueger [1993] used data from the High School and Beyond Survey which allowed him to include both a computer dummy and controls for parental background, achievement scores, and school

TABLE III
OLS REGRESSION FOR THE EFFECT OF DIFFERENT TOOLS ON PAY
DEPENDENT VARIABLE: LOG HOURLY WAGE
(STANDARD ERRORS IN PARENTHESES)

Independent variable	Germany 1979	Germany 1985–86	Germany 1991–92	Germany 1979	Germany 1979	Germany 1985–1986	Germany 1991–1992
Occupation indicators	No	No	No	501	501	742	1071
Grades and father's Occupation[a]	No	No	No	No	Yes	No	No
				Tools entered separately			
Computer	0.112	0.157	0.171	0.025	0.022	0.076	0.083
	(0.010)	(0.007)	(0.006)	(0.011)	(0.011)	(0.008)	(0.007)
Calculator	0.087	0.128	0.129	0.027	0.025	0.061	0.054
	(0.007)	(0.006)	(0.006)	(0.008)	(0.008)	(0.007)	(0.006)
Telephone	0.131	0.114	0.136	0.060	0.057	0.059	0.072
	(0.006)	(0.006)	(0.006)	(0.007)	(0.007)	(0.007)	(0.007)
Pen/pencil	0.123	0.112	0.127	0.055	0.052	0.055	0.050
	(0.006)	(0.006)	(0.006)	(0.007)	(0.007)	(0.007)	(0.007)
Work while sitting	0.106	0.101	—	0.042	0.041	0.036	—
	(0.006)	(0.007)		(0.008)	(0.008)	(0.008)	
Hand tool (e.g., hammer)	−0.117	−0.086	−0.091	−0.048	−0.045	−0.020	−0.020
	(0.007)	(0.006)	(0.006)	(0.009)	(0.009)	(0.008)	(0.008)

	Tools entered together						
Computer	0.066	0.105	0.126	0.027	0.024	0.067	0.069
	(0.010)	(0.008)	(0.007)	(0.011)	(0.011)	(0.008)	(0.007)
Calculator	0.017	0.053	0.044	0.015	0.014	0.032	0.022
	(0.008)	(0.007)	(0.007)	(0.008)	(0.008)	(0.008)	(0.007)
Telephone	0.072	0.043	0.045	0.043	0.041	0.035	0.048
	(0.007)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)
Pen/pencil	0.062	0.031	0.035	0.040	0.038	0.024	0.007
	(0.007)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)
Work while sitting	0.058	0.050	—	0.036	0.035	0.032	—
	(0.007)	(0.007)		(0.008)	(0.008)	(0.008)	

a. Two variables for self-reported grades in math and German and eleven dummy variables for father's education.

Data are from the *Qualification and Career Survey*. All regressions also include an intercept, years of schooling, experience and experience squared, dummies for part-time, city, female, married, married*female, and for civil servants (*Beamter*).

grades. We have measures of secondary school grades in math and German in the 1979 survey as well as information on the father's occupation. We include these variables in addition to the occupation dummies and obtain the results shown in column 5. While the ability controls are significant, the coefficients on computer use or the other tools are hardly changed once occupation is controlled for. Similar to Krueger's results for computers from the High School and Beyond Survey, these tools are picking up an effect about wages that is not captured by academic abilities. This indicates that ability controls, such as grades, may only be poor proxies for the types of skills that are ultimately relevant in the workplace.

IV. Discussion and Interpretation

In this section we discuss various interpretations of the computer differential and why our regressions inform this discussion.

We read the bulk of Krueger's [1993] paper as trying to uncover the "causal" or "treatment" effect of using a computer on the wages of a computer user. What we typically mean by a treatment effect is the difference in an outcome if a person is given a treatment, like a drug, versus not receiving this treatment. If this treatment is randomly assigned, a simple comparison of a treated and untreated population will identify the treatment effect. In observational data, where individuals select whether to receive treatment, a comparison of treated and untreated subjects will not identify the treatment effect if selection is related to the outcome of interest.

In the case of computers, things are a little more difficult. The simple analogy to identifying a treatment effect in the case of computers would be randomly assigning a computer to a group of previous nonusers and then comparing their wages with those of an untreated comparison group. Clearly, this exercise is unlikely to be meaningful. Here two issues arise: (1) computers are only productive in conjunction with a specific set of skills (e.g., programming); and (2) computers are of value only in certain jobs (e.g., for empirical economists but not for ballet dancers). In order to address the first issue, we can think of the experiment as randomly assigning computer *skills* instead of computers. In this case it is obvious that we would think of the resulting treatment effect as a compensating differential for the associated skill. If such a differential exists, those who have the scarce skills will tend to seek out jobs where the skill is rewarded. Hence, this interpretation also solves the second problem, namely that computers are only productive in certain jobs. Notice that this bears a close resemblance to interpreting estimates of the returns to education in general.

The foregoing discussion suggests that a better variable to study than computer use would be computer knowledge. Since this is not available on the CPS, we can interpret the computer use variable as a proxy for knowledge. Hence, if selection is relatively unimportant, and therefore the wage differential for computer users identifies the return to computer skills, then this return was roughly 19 percent in the United States in 1989 and 17 percent in Germany in 1991.[2]

Now consider our analysis of other tools. To make the contrast as stark as possible, consider use of a pencil on the job. The literacy rate in Germany is 99 percent; i.e., basically every worker is able to use a pencil productively. Since this tool is only being used by about 60 percent of the workforce, this skill is obviously not scarce. Therefore, we do not believe that using a pencil in Germany proxies for writing skills. A regression of wages on the use of pencils should therefore yield a coefficient of zero. Instead, the coefficient in 1991 is 13 percent, which we take as an indication that there is substantial selection in who uses office tools: they are used predominantly by higher paid workers. The argument we are making in this paper is the following: if this type of selection is important for pencils or calculators or telephones, then we should probably expect it to be equally important for computers. Or to put it the other way around, we would have been more inclined to believe that Krueger's regressions measure a treatment effect if we had found very small wage differentials for tools which should not proxy for a scarce skill. This is true in particular since the differentials for these other tools are about as robust to introducing controls that should capture job content or ability as the computer differential. Much of Krueger's conclusion, that the computer differential reflects a treatment effect, is due to such exercises. Of course, our results are merely suggestive and do not prove whether the computer coefficients represent a return to skills or a selection effect.

2. Hamilton and Yuen [1995] find that wage differentials accrue to computer skills rather than computer use in the U. S. High School and Beyond Survey. We found similar results in our German data for 1979; see DiNardo and Pischke [1996].

One obvious response to the possible selection effects that prevent us from estimating the treatment effect of computer use or skill on wages is to obtain panel data and estimate the wage growth for workers who start using a computer on the job for the first time. Krueger [1993] ran regressions for an artificial panel constructed from occupation level data from the CPS. He found an effect of computer use on the order of 10 percent, not much below the cross-sectional estimate. It is unclear, however, whether such an exercise yields all that much more information in the presence of changing returns to skills in the economy. If the increase in computer use proxies for some other, unrelated skill, whose return has increased during the period, we might find the same effect. In the working paper version of this article [DiNardo and Pischke 1996], we find that the computer-wage effect in these regressions vanishes once the initial education level of the occupation is included in the wage growth regression (which is highly significant).

There are two studies, of which we are aware, that estimate fixed-effects models for the return to computer use on microdata. Entorf, Gollac, and Kramarz [1995] use French data for the late 1980s and find no effect in their fixed-effects models, while there is a 7 percent computer differential in the cross section. Bell [1996] uses data for the United Kingdom and finds that most of the cross-sectional computer wage differential remains in first-differenced regressions. In the presence of changing returns the assumption of time-invariant fixed-effects is likely to be faulty. If the returns to unobserved skills change, then differencing the data will not eliminate the effect of unobserved wage determinants that might be correlated with computer use. Since the wage structure has widened in the United Kingdom but not in France, this is a possible explanation for the disparate results of the two studies.

Krueger [1993] and many commentators on that paper have tried to draw a link between the computer wage effect and changes in the wage structure related to skill-biased technical change. The direct link between the computer treatment effect, the effect of assigning a single worker a job with a computer keeping the utilization of computers in the economy constant, and changes in the wage structure is weak at best. Changes in the structure of wages may come from changes in the overall utilization of new technologies. It is easy to see that the introduction of computers could easily change the wage structure without generating a computer treatment effect. Levy and Murnane [1996] discuss the occupation of accountants who calculate the net asset values of mutual funds. They conclude that one of the more fundamental changes in the skills required for workers in this occupation did not directly involve the introduction of computers on the job of these workers. Rather, computerization at the exchanges made large trading volumes and complicated derivative securities possible. As a consequence, the ability to price a growing and complex set of assets has increased the skill demand on the occupation over time; computers played a role in this process but the channel is rather indirect. It is obvious from this example that there is no clean link between the influence of technology on wages and the computer treatment effects on workers, even if we can estimate this latter effect consistently.

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