THE IMPACT OF TECHNOLOGICAL CHANGE ON OLDER WORKERS: EVIDENCE FROM DATA ON COMPUTER USE

LEORA FRIEDBERG*

New technologies like computers alter skill requirements. This paper explores two related effects of the spread of computers on older workers, using data from the Current Population Survey and the Health and Retirement Study. One conclusion is that impending retirement, rather than age alone, explains why older workers used computers less than prime-age workers. A second conclusion is that computer users retired later than non-users. Although this pattern may arise because workers planning later retirement decided to acquire computer skills, the empirical analysis suggests that the causation also went in the other direction, with computer users choosing to delay retirement. It will be important to understand these effects as the baby boom cohort nears retirement, while technologies continue to change rapidly.

The proportion of workers of all ages who used a computer jumped from 24% in 1984 to 51% in 1997. Many people have the impression that older workers find it difficult to learn new technologies like computers. 40% of workers aged 60–64 in 1997 used a computer, 21% below the average. Nevertheless, in this paper I argue that age alone does not explain why older workers use computers less. Impending retirement, which reduces the time horizon to recoup an investment in new skills, appears to play a major role. Computer users have, in turn, been retiring later than non-users—perhaps because workers with computer skills choose to delay retirement and perhaps because workers planning later retirement choose to acquire computer skills. I use an instrumental variables approach to sort out the impact of computer skills on retirement.

The underlying premise is that new technologies like computers alter jobs and skill requirements in jobs. Case-study evidence supports this view, which is distinct from the unresolved question of the skill-bias of new technologies. If new technologies change skill requirements, older workers will be affected differently from prime-age workers if their skills are of an older vin-

*The author is Assistant Professor, Department of Economics, University of Virginia, and Faculty Research Fellow, NBER. She thanks David Autor, Julian Betts, João Miguel Ejarque, Lawrence Katz, Valerie Ramey, and seminar participants at several universities for very useful comments; Johannes Moenius and Andrew Caffrey for excellent research assistance; and the National Institute on Aging and the National Bureau of Economic Research Fellowship in Aging and Health Economics for financial support.

Data and programs are available from the author at the Department of Economics, Rouss Hall, University of Virginia, Charlottesville, VA 22904-4182; LFriedberg@Virginia.edu.

Industrial and Labor Relations Review, Vol. 56, No. 3 (April 2003).
0019-7939/00/5603 $01.00

tage. Older workers will also respond differently because impending retirement reduces their time horizon as they consider whether to upgrade their skills. It will be important to understand these effects as the baby boom cohort nears retirement, while technologies continue to change rapidly.

Technological change is difficult to observe, however. Earlier research on older workers used aggregated industry measures of technological change. I use repeated cross-sections from the Current Population Survey that show how computers have spread through the economy. I analyze the evolution of computer use by cohorts in order to understand why older workers use computers less than younger workers do. I then use longitudinal data from the new Health and Retirement Study to relate computer use to subsequent retirement decisions. Previous studies have emphasized the need to control for other attributes of computer users in order to identify the impact of computers. The Health and Retirement Study (HRS) allows detailed controls for many attributes of jobs and workers when analyzing the link between computer use and retirement.

Background

A key feature distinguishes much of the earlier research on technological change from more recent research on computerization. Earlier research often focused on whether recent technological changes have been skill-biased. Research on computerization offers a more nuanced view of the relationship between new technologies and job skills. Most important for this paper is the finding that computerization tends to alter skill requirements, in addition to complementing particular skills and substituting for others.

Technological Change and Older Workers

A great deal of research has investigated whether technological change in the past 20–30 years has been skill-biased—complementing skilled labor while substituting unskilled labor. A shift toward skill-biased technological change is a leading explanation for rising earnings inequality in the United States.[1]

A few researchers have studied the impact of technological change on older workers. Juhn (1992) concluded that the rising dispersion of earnings contributed to earlier retirement of low-education workers, relative to high-education workers. However, the interaction of age and education is complex. Katz and Murphy (1992) found that education had a two-edged effect on relative earnings for older workers: low education penalized them less than it did prime-age workers, but high education *rewarded* them less. The asymmetric outcomes by education imply an interaction of skill requirements with age or skill vintage.

Bartel and Sicherman (1993) studied the impact on older workers of technology shocks that may have altered skill requirements, without necessarily being skill-biased. While they concluded that training costs associated with unanticipated technological change led workers to retire early, they relied on industry-level statistics on productivity growth and training requirements in the 1960s and 1970s.

The Impact of Computerization

Earlier studies used indirect measures of technological change. Information on computer usage that has become available more recently offers new insight. Recent research has identified at least three ways in which computers have altered jobs. First, computers have automated routine tasks, often involved in clerical and assembly-line jobs; this has tended to replace unskilled and semi-skilled workers. Second, computers have altered the performance of non-routine tasks, often by skilled workers. Computers complement many technical and

[1]See Gottschalk (1997), Johnson (1997), and Topel (1997) for reviews of the evidence.

management jobs, raising labor productivity and in some cases the inherent ability required of workers as computers take over less skilled functions.[2]

Third, whether or not computers have changed the underlying ability required to do a job, computerization often alters the entire bundle of skills and tasks that define a job. Computer use is, obviously, one of the new skill requirements. While computers have grown easier to use over time, both employers and individuals continue to devote substantial resources to computer training. For example, the University of Virginia has provided computer training to 2,000–3,000 staff per year in over 2,000 total workshops during the past four years. The University now furnishes 3.86 training hours per employee per year, up from 0.73 in 1994.[3] But in addition, computerization often leads to other changes in required skills. Bresnahan, Brynjolffson, and Hitt (2002) emphasized that firms that computerized often implemented a cluster of complementary changes focused on workplace organization and services, incurring substantial training costs and other adjustment costs.

This suggests several ways in which computerization could affect older workers differently from prime-age workers. Most important, the changes in skill requirements require an investment of resources in existing workers. This affects workers of all ages, but older workers have less time than others to recoup the investment as they approach retirement. Second, older workers are less likely to have computer skills in the first place. Third, older workers have lower average levels of education, so they may be more likely to have the routine jobs that have been automated.[4] Thus, satisfying new skill requirements may require a greater investment of resources for older workers than for younger workers.

The extent to which computer use itself is a valuable skill that earns a premium has been disputed.[5] Nevertheless, the basic point remains that computerization tends to alter jobs and required job skills. Thus, I interpret computer use as productive, after controlling for other attributes of computer users and their jobs. The HRS helps in this regard, because it reports unprecedented detail about potential correlates of computer use and retirement—including other required job skills, employment history, and non-wage compensation like pension and health benefits.

Data on Computer Use

I use two data sets in this study. The Current Population Survey (CPS) collects monthly employment data from over 150,000 people, yielding a sample of about 60,000 workers aged 18–64. The October surveys of 1984, 1989, 1993, and 1997 asked workers, "Do you directly use a computer at work? … [and, if so, for what purposes?]"[6] The January 1991 survey asked about job training, including training in computer skills.

[2]These two dimensions were highlighted in case studies of a financial services firm by Levy and Murnane (1996) and of a large bank by Autor, Levy, and Murnane (2002).

[3]I am grateful to Antonio Rice and Roxana Colvin for data from the University's office of Information Technology and Communication. Additional statistics appear in the ITC Progress Report 1999–2000.

[4]Goldin and Margo (1992) documented the steep rise in educational attainment during the twentieth century.

[5]Brynjolffson and Hitt (1997), Lehr and Lichtenberg (1998 1999), and Autor, Katz, and Krueger (1998) all demonstrated correlations between skill levels and computerization. While computer use is correlated with higher earnings, the interpretation of this correlation has been disputed in papers by Krueger (1993), DiNardo and Pischke (1997), and Lang (2001).

[6]The 1993 supplement began, "The next set of questions has to do with direct or hands on use of computers…. These questions do not refer to handheld calculators or games, electronic video games, or systems that do not use a typewriter-like keyboard." As Krueger (1993) pointed out, this targets users of computers with keyboards and monitors, but not many other devices with embedded microprocessors.

Table 1. Rates of Computer Use at Work: Percentage of Workers Who Use a Computer.

	Year			
Independent Variable	*1984*	*1989*	*1993*	*1997*
All Workers	24.4	37.3	46.6	50.6
Age:				
18–22	16.9	25.7	28.9	31.8
23–39	28.5	40.9	49.2	52.6
40–49	23.6	40.3	51.3	54.9
50–59	19.7	32.0	43.9	50.7
60–64	14.4	23.3	32.7	40.0
Education:[a]				
< High School	4.9	7.7	9.5	11.7
High School	18.5	28.5	34.1	36.4
Some College	31.2	44.8	53.1	56.2
College +	41.2	58.6	70.2	75.9
Gender:				
Male	20.8	31.9	41.1	44.8
Female	29.3	43.6	53.2	57.3
Occupation:				
Professional & Technical	38.1	54.4	65.7	73.1
Managers & Administrators	42.5	61.8	73.7	78.7
Sales	23.9	35.5	49.8	55.8
Clerical	47.4	66.8	77.4	78.6
Craftsmen	10.1	15.2	23.5	25.3
Operatives	5.8	9.6	15.7	18.6
Laborers	3.2	6.6	11.7	12.8
Service	6.0	9.8	15.1	16.8
Sample Size	60,095	58,584	59,852	56,247

Sample: people aged 18–64, at work or with a job last week, October Current Population Surveys. Computed with the supplemental weights, or in 1997 with the final weights.
[a]The classification of educational attainment was revised after the 1992 CPS.

The longitudinal Health and Retirement Study began in 1992, following over 7,600 households with someone born between 1931 and 1941. Every two years the HRS collects detailed data on employment, income, health, and so on. The first wave asked workers how often they were required to work with computers. This information has not been closely studied but is well suited for analyzing the interaction of computer use and subsequent retirement.[7] The detailed data on individual and job characteristics are crucial in controlling for other factors that may be correlated with computer use.

Patterns of Computer Use

Trends in Computer Use

Table 1 reports computer use of workers aged 18–64 in the CPS. In 1984, 24.4% of workers used a computer. Computer use rose 12.9 percentage points by 1989 and 9.3 points by 1993, but only 4.0 points by 1997, to 50.6%. While the small increase after 1993 suggests that computerization reached a plateau, computer purchases remained strong, and I show later that the intensity of computer use continued to deepen.

[7]Hurd and McGarry (1993) analyzed the effect of computer use and other job characteristics on retirement plans, but not on actual retirement. Later HRS waves did not ask about computer use.

Figure 1. Computer Use at Work, by Age.

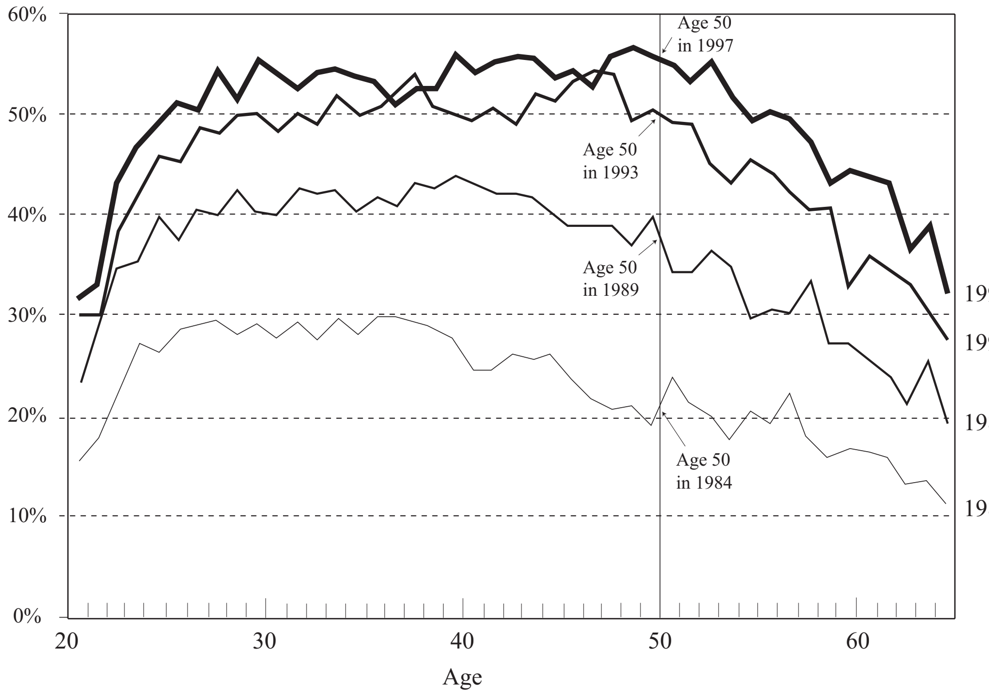


Table 1 also shows how computer use varied across different types of workers.[8] 75.9% of workers with a college education in 1997 used a computer, compared to 36.4% with only a high school degree. This gulf in computer use by education widened over the period. Women used computers more than men did, but controlling for occupation explains virtually all the difference.

Computer Use and Age

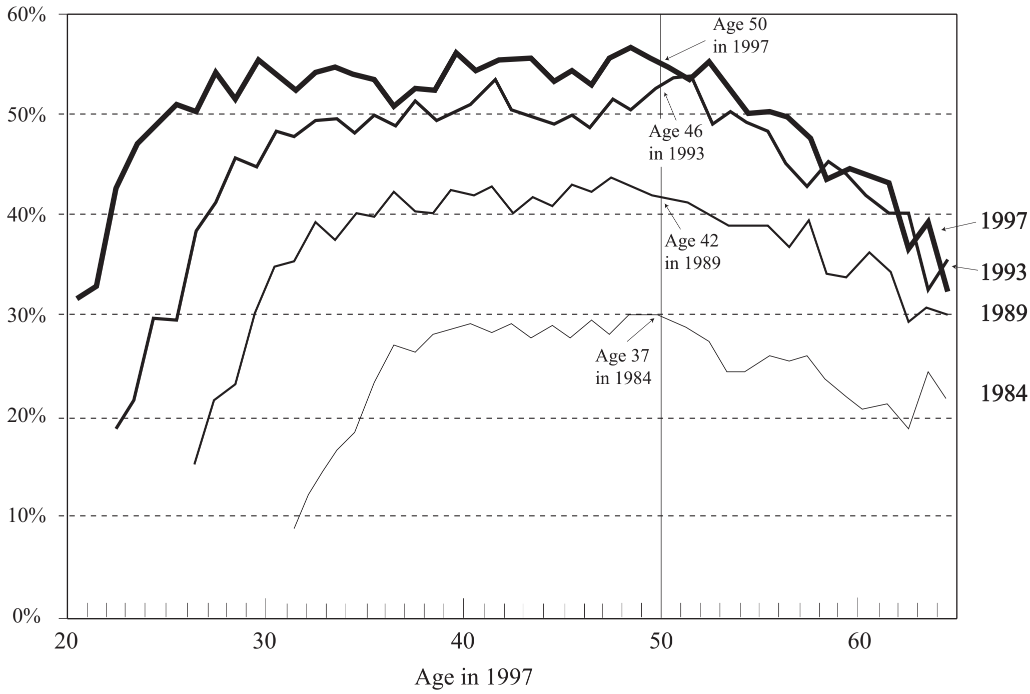
The "age profile" of computer use in multiple years appears in Figure 1. It is striking that computer use was essentially flat over most ages in 1997. The rate of computer use hovered around 54%, not deviating by more than 3 percentage points at any age from 25 to 53. As the age profiles evolved, the dominant trend was a steady upward shift in computer use at all ages. The age profiles were more peaked early on and spread out as early users aged.

The long flat range of computer use in the age profiles suggests that being old or many years out of school did not by itself keep people from using computers. Workers in their fifties in 1997, 51% of whom used a computer, were very unlikely to have used a computer in college, for example. People apparently acquired computer skills as needed for their jobs, largely independent of age—except for the oldest workers, who used computers significantly less.

This is also evident in the evolution of computer use within each cohort. Figure 2 shows observations for the same cohort in different years, rather than for the same

[8]The same tabulations appear in Krueger (1993) and Autor, Katz, and Krueger (1998). The 1984 and 1989 statistics shown here are very similar but do not exactly replicate those in Krueger's Table 1.

Figure 2. Computer Use at Work, by 1997 Cohorts.



age in different years as in Figure 1. For example, it plots the evolution of computer use for the cohort aged 50 in 1997, 46 in 1993, 42 in 1989, and 37 in 1984. These comparisons clearly show that the oldest workers in 1997 had only recently fallen behind. People in their late fifties and sixties in 1997 used computers at a substantially lower rate at that time, but at only a slightly lower rate in 1984 and 1989.

The gains in computer use among successive cohorts appear in Table 2. The influence of approaching retirement is most apparent for older cohorts in 1993, shown in the middle rows. People aged 60–64 in 1993 kept close to younger workers earlier, from 1984 to 1989; their computer use rose 8.9 percentage points, compared to 12.9 for people aged 45–49 in 1993. From 1989 to 1993, however, their gain was 4.1 points, compared to 11.4 for the younger group.[9] Thus, they failed to keep up with younger workers *as they neared retirement,* though they had kept pace previously.[10]

These cohort trends suggest an alternative explanation for the low rates of computer use at older ages. Age by itself does not explain it—nor do years since schooling, nor the obsolescence of skills. Those backward-looking factors should generate a sloping, not flat, age profile. The age profiles suggest the importance of a forward-looking factor like impending retirement. The decision at any age to use a computer requires an investment in new skills that pays off over time. Therefore, a worker's time horizon affects whether he or she ends up using a computer. This conclusion is reinforced by analyzing, later, the evolution of computer use within occupations.

[9]Computer use grew much less after 1993, so the aging of existing users is the dominant effect between 1993 and 1997.

[10]Note that selective retirement by non-computer users, which is implied by the estimates in the second half of the paper, would accentuate the conclusions drawn here.

Table 2. The Spread of Computers among Older Cohorts: Percentage and Changes in the Percentage of Workers Who Use a Computer, by Cohorts and Years.

	Rates of Computer Use by Cohorts Aged:			
Description	*45–49*	*50–54*	*55–59*	*60–64*
Cohorts in 1989				
% Using a Computer, 1984	25.4	21.3	20.9	18.4
% Using a Computer, 1989	38.6	33.8	29.7	23.3
Change, 1984–89	13.2[a]	12.5	8.8	4.9
Cohorts in 1993				
Change, 1984–89	12.9	12.6	11.8	8.9
Change, 1989–93	11.4	8.7	7.1	4.1
Cohorts in 1997				
Change, 1984–89	13.9	13.3	12.2	11.0
Change, 1989–93	8.2	11.2	8.5	6.2
Change, 1993–97	3.9	1.5	1.8	1.5

Sample: see Table 1 notes.
[a]For example, computer use of the cohort aged 45–49 in 1989 rose 13.2 percentage points between 1984 and 1989.

Computer Use in the HRS

The Health and Retirement Study asked workers in 1992 how frequently they used a computer on the job. Table 3 shows that 48.9% of workers aged 50–59 and 41.9% aged 60–62 used a computer at least some of the time. Over half of users reported using a computer most or all of the time, with identical intensity of use by age. Age, education, and occupational differences in computer use resemble those in the CPS. The overall rates of use are higher, perhaps because the HRS focuses on frequency of use and also lacks the careful lead-in defining computer use. I will return to the HRS data later to analyze retirement decisions of computer users and non-users.

Computer Use across Occupations

Computer use varies enormously by occupation. Table 1 shows that the computer use rate in 1997 was 70–80% among professionals, managers, and clerical workers, but 25% or less among skilled and unskilled blue-collar workers.[11] Computers spread at different rates as well.

It is important to demonstrate that age differences in occupation and education do not explain age differences in computer use. Table 4 reports regressions of 1993 computer use that include controls for age, occupation, and education. Adding 45 occupation and 4 education dummies in column (4) shrinks coefficients on age dummies by 1/4 to 1/3. For example, the estimated computer use rate at age 23–39 is 16.5 percentage points higher than at age 60–64, and it remains 12.8 points higher after education and occupation controls are added. Thus, within-occupation and within-education differences explain most of the age differences in computer use.

Next, I show that computer use of older cohorts fell behind in occupations with recent jumps in computer use, compared to those with high use early on. Some jobs had high rates of computer use early on, while in others it jumped later.[12] Table 5 reports regressions, for different cohorts, of individual computer use on both levels and changes in average use in the person's

[11]Computer use in 45 two-digit occupations ranged from 4% to 97%. The coefficient of variation across occupations is almost identical at the one- and two-digit levels.

[12]High computer-use occupations throughout include engineering and some managerial and clerical jobs. Teachers, public administrators, and health workers, among others, had major gains after 1984.

Table 3. Rates of Computer Use at Work: Percentage of Workers Who Use a Computer, 1992 HRS. (Standard Errors in Parentheses)

Group	*Age 50–59*	*Age 60–62*
Among Those Who Work	48.9 (0.7)	41.9 (1.6)
Among Users, % Using a Computer:		
All or Almost All of the Time	40.5	40.3
Most of the Time	20.1	20.1
Some of the Time	39.3	39.6

Sample: age-eligible workers (born in 1931–1941) in the Health and Retirement Study (N = 6,660). Computed with the person-level analysis weights.

occupation and industry. The point is to show how the pace of computerization affected computer use as particular cohorts aged. Not surprisingly, the estimates show that average computer use in an occupation, and its interaction with the industry average, was a key determinant of whether someone used a computer.

The estimates also show that older workers—but not younger workers—failed to keep pace with *recent changes* in computer use. Thus, recent increases in computer use had a large, statistically significant, negative coefficient for older cohorts, but the same was not true for earlier changes or for younger cohorts. Suppose someone aged 60–64 in 1993 worked in an occupation and industry in which 50% of prime-age workers had used a computer since 1984; the coefficients imply that the worker had a 54% chance—about the same—of using a computer. In contrast, if computer use in the job jumped from 10% to 30% to 50% between 1984, 1989, and 1993, the worker had only a 14% chance of using a computer. A worker aged 50–59 had a 59% chance of using a computer in the first case, but only a 26% chance in the second.

These results highlight the interaction between technological change and impending retirement. The evolution of the age profiles showed that the oldest workers fell behind only as they approached retirement age. Here, the evidence shows that the oldest workers fell behind only if computer use jumped in their jobs.

How Workers Use Computers

The CPS asked workers what they used computers for, and I grouped about 20 possible answers into broad tasks. For example, word processing, databases, and spreadsheets are classified as common applications. Table 6 shows that common applications remain the most popular task, reported by 71% of computer users in 1997. The table also shows that the intensity of computer use had risen—the number of specific tasks reported by each computer user rose from an average of 4.0 in 1993 to 4.6 in 1997, even though the number of categories reported in the CPS actually fell from 22 to 16 over the same period.

The oldest and youngest workers used computers less intensively than prime-age workers did, however. Computer users aged 60–64 reported an average of 4.0 specific tasks, 14% less than the 4.7 reported at ages 23–49. The differential intensity of use actually rises slightly if one controls for education and occupation. These patterns suggest that the oldest and youngest computer users acquired fewer computer-related skills than had prime-age workers.

Additional data on computer use and training from the January 1991 CPS appear in Table 7. We see the same age profile of computer use.[13] Rates of job training differed by age as well. 48.8% of workers aged 40–49 received some training in their current job, compared to 42.8% at ages 50–59 and 34.7% at ages 60–64.[14] Older workers also received less training in computer skills. Of workers aged 40–59 who received training, 35.4% were trained in computers, ver-

[13]The age differentials are almost identical to the October 1989 and 1993 data, although, as in the HRS, the rates of computer use are higher: 72.7% of users aged 60–64 reported everyday use, versus 77.5% at ages 23–39.

[14]The age differences in job training rates persist with controls for occupation and occupational and employer tenure.

Table 4. The Impact of Occupation and Education on Computer Use. (OLS Regression Coefficients, Standard Errors in Parentheses)

	Dependent Variable: Do You Use a Computer at Work?			
Independent Variable	*(1)*	*(2)*	*(3)*	*(4)*
Age, Relative to 60–64:				
18–22	–0.039 (0.013)	0.067 (0.011)	Omitted	Omitted
23–39	0.165 (0.011)	0.153 (0.010)	0.107 (0.011)	0.128 (0.010)
40–49	0.185 (0.012)	0.141 (0.010)	0.144 (0.011)	0.118 (0.010)
50–59	0.112 (0.012)	0.083 (0.011)	0.085 (0.012)	0.076 (0.010)
Education, Relative to < High School:[a]				
High School	—	—	0.254 (0.006)	0.109 (0.006)
Some College	—	—	0.454 (0.007)	0.202 (0.007)
College +	—	—	0.602 (0.006)	0.278 (0.008)
Occupation Dummies	no	yes[b]	no	yes[b]
Constant	0.327 (0.010)	0.761 (0.021)	–0.001 (0.011)	0.553 (0.024)

Sample: workers aged 18–64 in the October 1993 CPS. Estimated with supplemental weights and Huber-White standard errors. All estimates are statistically significant at the 95% or higher confidence level.

[a]Estimates with education dummies omit ages 18–22, since people who were not in school at that age were not representative of the entire sample.

[b]Occupation dummies for 45 detailed categories.

sus 29.4% at ages 60–64. These patterns support the key hypothesis in this paper—workers tend to get less training in new skills as they near retirement.

Computer Use and Retirement

The age profiles of computer use suggest that retirement reduces the value of acquiring computer skills or other productive skills. It follows that a change in technology requiring new skills may lead some workers lacking those skills to retire early. Others who acquire the new skills may choose to delay retirement. The rest of this paper analyzes the interaction of computer use and retirement using longitudinal data from the HRS.

Table 8 shows retirement data from the first three waves of the HRS. Among workers aged 50–62 in wave 1, 75.6% were still working four years later in 1996.[15] Computer users were statistically significantly less likely to retire than were non-computer users: 78.4% were working four years later, compared to 73.0% of non-computer users, implying that non-users were 25% more likely to leave work.

A stylized model can explain the interaction of computer use and retirement. Consider a worker who lacks a productive new skill (like computer use) that could be acquired with training. The employee will get trained in the new skill, $S = 1$, if the expected benefit $\mathrm{B}(S)$ exceeds the cost $\mathrm{C}(S)$ incurred today:

$$(1) \qquad S = 1 \text{ if } \mathrm{B}(S) = \sum_{t=n+1}^{R} \frac{E[b_t(S)]}{(1+r)_{t-n}} > \mathrm{C}(S).$$

Future per-period benefits of training $b_t(S)$ are discounted and may be uncertain; a new technology could make the skill obsolete, for example. Benefits stop accruing at the retirement date R, also a choice variable. Therefore, $S = S(R)$, and for a given R, $\partial S(R)/\partial R \geq 0$.[16]

[15]Following much of the retirement literature, I use the objective measure of exit from employment, rather than self-reported retirement.

[16]The training decision may be made by the employee or by the employer, depending on who pays the costs and gets the benefits. The firm must infer R

Table 5. The Impact of the Spread of Computers on Computer Use.
(OLS Regression Coefficients, Standard Errors in Parentheses)

	Dependent Variable: Do You Use a Computer at Work? Age in 1993		
Average Computer Use in the Same:	*(1) Age 23–49*	*(2) Age 50–59*	*(3) Age 60–64*
Occupation	0.823** (0.022)	0.723** (0.054)	0.528** (0.104)
Change, 1989–93	0.028 (0.067)	–0.390** (0.145)	–0.897** (0.239)
Change, 1984–89	–0.012 (0.050)	0.123 (0.134)	–0.020 (0.250)
Industry	0.375** (0.027)	0.426** (0.059)	0.164 (0.109)
Change, 1989–93	–0.120 (0.085)	–1.001** (0.193)	–0.707** (0.369)
Change, 1984–89	–0.228** (0.051)	–0.382** (0.128)	–0.407 (0.266)
Occupation * Industry	0.099** (0.036)	0.154** (0.077)	0.556** (0.135)
Constant	–0.085** (0.007)	–0.019 (0.016)	0.057** (0.026)

Sample: workers in the October 1993 CPS. Estimated with supplemental weights, Huber-White standard errors. The right-hand-side variables are levels and changes of average computer use for workers aged 23–49 in 45 occupations and 50 industries.
*Statistically significant at the .10 level; **at the .05 level.

The training decision ultimately depends on various factors,

$$S = S(P^S, F^S, R), \tag{2}$$

which influence the costs and benefits of training, including personal characteristics P^S (other skills, overall ability) and firm characteristics F^S (productivity of the new skill). The intended retirement date depends on related variables,

$$R = R(P^R, F^R, S), \tag{3}$$

again including personal characteristics P^R (health, assets) and firm characteristics F^R (earnings, retirement benefits). Thus, the training decision and future retirement plans are chosen simultaneously. There are two reasons why someone who acquires new skills may retire later than someone who does not. First, the prospect of improved work opportunities from training may induce a delay in retirement, so $\partial R(S)/\partial S \geq 0$. Second, someone who was planning to delay retirement for other reasons (and so has a high R already) may find it useful to get training, based on (1).[17] Similarly, we may observe non-computer users retiring early because computerization reduces the value of their skills *or* because they intended to retire early and therefore did not get computer skills.

The key hypothesis that I seek to test is whether acquiring new skills induces a worker to delay retirement. This hypothesis can be tested in two distinct ways. One approach is to model and estimate (2) and (3), but many important variables are not observed.[18] The other approach is to instrument for S, whether a person was trained or uses a computer. A valid instrument is correlated with computer use but otherwise uncorrelated with intended and actual retirement. The instrumental variables approach amounts to asking whether exogenous computer training—giving someone productive computer skills and a computer—will lead to later retirement, on average.

if it makes the training decision, so it may under-train older workers who cannot credibly convey private information about retirement plans. This consideration is omitted here, but it does not change the basic conclusions.

[17]Getting training may subsequently induce earlier retirement through a wealth effect.

[18]Most important, we observe neither when a worker got trained, nor retirement plans.

Table 6. Tasks for Which Computers Are Used: Percentage of Computer Users Who Use Computers for Various Tasks, and the Average Number of Tasks per User.

	1989	*1993*	*1997*	*1997*				
Broad Tasks[a]	*Ages 18–64*			*18–22*	*23–39*	*40–49*	*50–59*	*60–64*
Common Applications	60	64	71	54	72	73	73	68
Accounting Tasks	45	45	66	71	68	66	63	61
Communication Tasks	31	39	47	31	48	49	49	44
Analysis	25	26	27	13	28	29	26	21
Graphics Tasks	22	25	26	15	27	27	26	22
Programming	19	13	15	10	16	16	13	11
Sales Tasks	16	16	22	23	24	21	20	21
Instruction	15	16	—	—	—	—	—	—
Games	5	6	—	—	—	—	—	—
Other	18	19	13	10	12	14	14	14
Don't Know	6	6	—	—	—	—	—	—
Average No. Broad Tasks	2.6	2.7	2.9	2.3	2.9	2.9	2.8	2.6
Average No. Specific Tasks	3.6	4.0	4.6	3.4	4.7	4.7	4.4	4.0

Sample: see Table 1 notes.

[a]The CPS asked about 16–22 specific tasks, depending on the year, and these have been grouped into broad tasks; see the appendix for more information. A dash indicates that the task was not asked about that year.

The instrument I use here is average computer use by prime-age workers in the same occupation and industry. High computer use signals that computers are productive relative to training costs, so even older workers near retirement are more likely to use them. The underlying assumption is that average use for prime-age workers who are far from retirement is not otherwise correlated with older workers' retirement plans, *after* controlling for other characteristics. I use the detailed HRS data to control for many attributes of workers and jobs that may be correlated with computer skills and retirement. After presenting the results, I explore sensitivity to this identifying assumption.

Estimating the Impact of Computer Use

Non-computer users in the HRS retired sooner than computer users, possibly for two reasons: lack of computer skills made work less attractive, and the intention to retire soon diminished the value of acquiring computer skills. Here, I instrument for computer use in order to estimate its direct impact on retirement.

First Stage Estimates of Computer Use

Table 9 reveals a strong effect of average computer use by prime-age workers on computer use by older workers who are in the same occupation and industry.[19] In specification (1) without covariates, occupational computer use has a major impact, particularly in high-use industries. This mirrors results from the CPS in Table 3. Specification (2) reports the first-stage regression, which includes additional worker and job covariates. The occupation and industry effects diminish a little but still account for most of the explained variation. The estimates imply that if average computer use is

[19]These and the rest of the estimates in this paper are reported from a linear probability model; probits yield very similar results. Average computer use is computed in the 1993 CPS for 17 occupation and 13 industry codes that match those in the HRS public release.

Table 7. Computer Use and Training at Work: Percentage of Workers Who Use Computers, Who Feel Their Computer Skills Are Adequate, and Who Have Received Training.

Description	*All*	*18–22*	*23–39*	*40–49*	*50–59*	*60–64*
% Using a Computer	50.9	37.1	53.6	55.8	45.4	34.8
% Users Using Computer Less Than Once per Week	9.2	8.9	8.7	9.8	9.6	10.5
Once or More per Week	14.1	13.8	13.9	14.2	14.6	16.9
Every Day	76.8	77.3	77.5	76.0	75.8	72.7
% Who Feel Their Computer Skills Are Good Enough for the Current Job:						
Computer Users	88.4	93.6	89.1	86.8	86.6	85.8
Non–Computer Users	59.2	71.4	59.6	57.3	54.4	51.9
% Who Got Any Training in the Current Job	42.6	25.1	43.1	48.8	42.8	34.7
Of Those, % Trained in Computer Skills	32.7	21.9	32.1	35.4	34.3	29.4

Sample: workers aged 18–64, January 1991 CPS. Computed with the final weights.

50%, an older worker is 8.8 percentage points more likely to use a computer than he or she would be if average computer use were 40%.

Specification (3) adds more potential instruments—changes in average rates of computer use—to control for the pace of computerization. As in the CPS, older workers are less likely to use computers in jobs that recently computerized than in jobs with long-standing computerization. The magnitudes differ at least in part because the HRS occupation and industry codes are more aggregated.

OLS Estimates of Retirement

The main results in Table 10 focus on whether someone who worked in 1992 was still working four years later. A series of covariates are added in sequence. Specification OLS-1 shows that the positive effect of computer use on work persists when a control for age is included.[20] OLS-2 includes standard demographic controls and omits computer use. Educated workers were much more likely to continue working, a finding of many earlier studies. Computer use, added in OLS-3, now has a smaller effect, since educated workers were much more likely than others to use a computer.[21]

OLS-4 adds numerous individual and job characteristics only available in the HRS. For example, I include controls for the usual retirement age in the worker's job; pension and health benefits available after retirement; and recent hospitalization.[22] Adding these variables in OLS-4 raises the computer use coefficient. The coefficient is significant with 90% confidence and implies that computer users were 2.2 percentage points, or 12.3%, less likely than non-computer users to have stopped working four years later. This accounts for about half of the raw difference in retirement between computer users and non-users. The estimates are similar in both two-year intervals.

Most of the HRS variables have the expected signs, and many are statistically sig-

[20]Age dummies control for possible spurious correlation as computer use drops while retirement rises. In fact, age has little effect when the full set of covariates is included in OLS-4.

[21]The sample in the preliminary specifications, OLS-1 through OLS-3, is restricted to be the same as in OLS-4, when numerous covariates are added. Similar estimates are obtained from the entire HRS sample.

[22]The full set of coefficient estimates for OLS-4 and IV-4a is reported in Friedberg (2001). Additional specifications discussed in the text are available from the author.

Table 8. Computer Use and Retirement:
Among People Working Initially, the Percentage Still Working Years Later.
(Standard Errors in Parentheses)

If Working in ..., % Still Working Later in ...:	*1992 → 96*	*1992 → 94*	*1994 → 96*
All Workers Aged 50–62 in 1992	75.6 (0.6)	85.1 (0.5)	83.8 (0.5)
Computer Users	78.4 (0.8)	87.0 (0.6)	85.9 (0.7)
Non–Computer Users	73.0 (0.8)	83.3 (0.6)	81.7 (0.8)

Sample: HRS. See Table 3 notes. Age-eligible workers who were also surveyed at the later date (N = 6,097 in the first column).

nificant. For example, someone who had a defined benefit pension and was beyond the benefit eligibility age was 12.1 percentage points less likely to continue working than was an otherwise similar worker who had not yet reached the eligibility age. Relative to other workers without insurance, someone with health insurance from an employer was 6.0 points more likely to continue working, while someone with retiree health insurance was 7.6 points less likely. Log hourly earnings do not significantly affect retirement and do not change the estimated computer use effect. This is important to note, because Krueger (1993) showed that computer users have higher earnings than non-users; if other skill-related characteristics correlated with computer use also affect retirement, including earnings would reduce the estimated computer use effect.

Since the instruments vary only by occupation and industry, it is crucial to know how occupation and industry characteristics directly affect retirement. Added to the parsimonious specification in OLS-3, occupation dummies are jointly significant at the 92% confidence level and industry dummies at the 82% level. Added along with the detailed HRS controls in OLS-4, confidence levels drop to 84% and 70%, respectively, which are below conventional levels of significance. Therefore, the HRS variables—and the usual retirement age and pension plan variables in particular—capture key job attributes correlated with retirement. The remaining influence of occupation and industry, while not negligible, is no longer statistically significant.

Instrumental Variables Estimates of Retirement

Table 11 reports instrumental variables estimates. As before, IV-3 includes basic demographic controls as in OLS-3, while IV-4a and IV-4b add the rich set of controls from the HRS as in OLS-4. IV-4a instruments with average computer use in the same occupation and industry, and IV-4b adds the changes in computer use.

The estimated computer use effect remains large in each specification and suggests that computer use directly induced delays in retirement. The point estimate in IV-4a implies that using a computer made someone 7.1 percentage points more likely to continue working, a strong effect. With the relatively large standard errors, we cannot reject the hypothesis that the IV estimates are different from OLS. Adding the additional instruments for ongoing changes in computer use incorporates more information about the pace of computerization. The estimate in IV-4b falls by a little less than 10% and remains statistically significant. The estimate implies that using a computer made someone 6.6 percentage points less likely to stop working, a 27.5% change relative to the 24.1% of the sample who did stop working. Holding everything else constant, the median retirement age if everyone had used a computer would have occurred 12 months later.[23]

[23]Ultimately, the estimates could be evaluated in terms of the implied retirement response to higher earnings. However, structural retirement models like the one in Rust and Phelan (1997) do not offer a

Table 9. Explaining Computer Use.
(OLS Regression Coefficients, First-Stage Estimates, Standard Errors in Parentheses)

	Dependent Variable: The Person Uses a Computer		
Description	*(1)*	*(2)*	*(3)*
Average Occupational Computer Use	0.580** (0.064)	0.412** (0.064)	0.326** (0.078)
Change, 1993–97	—	—	–0.476** (0.185)
Average Industry Computer Use	0.109* (0.061)	–0.028 (0.065)	–0.284** (0.100)
Change, 1993–97	—	—	–1.053** (0.326)
Occupation*Industry Average	0.569** (0.120)	0.548** (0.118)	0.466** (0.120)
R^2	0.288	0.355	0.358
Includes Other Covariates?	no	yes	yes

Sample: HRS. See Table 10 notes. Estimated with the person-level analysis weights and Huber-White standard errors. Independent variables: average computer use of workers aged 23–49 in the same occupation and industry, 1993 CPS.

*Statistically significant at the .10 level; **at the .05 level.

Instrumenting has little effect on the rest of the coefficients; this implies that other occupation and industry characteristics correlated with computer use are not being picked up in the IV results. The computer effect is stronger later on, from 1994 to 1996; this is consistent with evidence from Table 6 that the intensity of computer use continued to deepen, even though the pace of computerization slowed.

When estimated separately by age group, the computer use effect grows with age, though the differences are not statistically different. The coefficients are 0.013 (0.045) for ages 50–54, 0.086 (0.056) for 55–59, and 0.218 (0.135) for 60–62. In contrast, the OLS estimates are quite similar across ages. These differences suggest a shift—retirement plans influenced computer use of the sample's younger workers so the IV estimate is small, while computer use influenced retirement of older workers. In OLS estimates, occupation and industry effects are far from statistically significant for younger ages but matter somewhat for ages 60–62.[24] Thus, the strongest result is the IV estimate for ages 55–59.

Research on prime-age workers shows that women had more elastic labor supply than men; computer use may therefore have had greater influence on women's retirement. Separating the sample by gender raises the standard errors, but the point estimates indicate a stronger effect of computer use in delaying retirement of women, who had a coefficient of 0.093 (0.049), than in delaying retirement of men, with a coefficient of 0.064 (0.055).

The HRS also asks about retirement plans. On average, workers in this sample planned to retire in 7.7 years. Regressing years to retirement on computer use (as in OLS-4) yields a coefficient of 0.372 (0.134), so computer users planned to work significantly longer than did non-users. Instrumenting with average use (as in IV–4a) yields a coefficient of 0.676 (0.313). Thus, using a computer caused a delay in planned retirement of two-thirds of a year, or 9.0%.

strong basis for comparison, because they used data from the 1970s and lacked information on important factors such as pension and health insurance coverage. Structural models have not yet been estimated using the HRS, which is still in progress.

[24]Earlier, I discussed adding occupation and industry to OLS-4 estimates for the whole sample. For ages 50–54 and 55–59, confidence levels for joint significance are under 50%. They have borderline statistical significance for ages 60–62, and in that case they may reflect other influences on retirement, as is discussed in the next subsection.

Table 10. Explaining Retirement.
(OLS Regression Coefficients, Standard Errors in Parentheses)

	Dependent Variable: The Person Is Still Working 1992 → 96			
Independent Variable	*OLS-1*	*OLS-2*	*OLS-3*	*OLS-4*
Uses a Computer	0.033**	—	0.010)	0.022*
	(0.012)		(0.013	(0.014)
Education:				
High School	—	0.074**	0.071**	0.070**
	(0.019)	(0.019)	(0.019)	
Some College	—	0.095**	0.091**	0.087**
	(0.021)	(0.021)	(0.022)	
College +	—	0.127**	0.122**	0.126**
		(0.021)	(0.022)	(0.023)
Also Includes	Age		Age, Demographic Characteristics	Age, Demographic and Job Characteristics
	Dependent Variable: Same, 1992 → 94			
Uses a Computer	0.028**	—	0.016	0.012
	(0.010)		(0.011)	(0.011)
	Dependent Variable: Same, 1994 → 96			
Uses a Computer	0.027**	—	0.010	0.020
	(0.012)		(0.012)	(0.013)

Sample: HRS, workers aged 50–62 in 1992 with hourly earnings between $1 and $100 and non-missing values for demographic and job characteristics (N = 5,152). Estimated with the person-level analysis weights, Huber-White standard errors. Demographic variables are race, sex, and marital status. Demographic and job characteristics are listed in the appendix.

*Statistically significant at the .10 level; **at the .05 level.

Are the Instruments Valid?

The conclusion that computer use makes it attractive to keep working is driven by people in high-computer-use jobs, who are much more likely than others to use computers. However, the IV estimates are larger, not smaller, than the OLS estimates—evidently because some non-users in high-use jobs retired later than non-users in low-use jobs. This raises concern about omitted variables—the presence of other occupation and industry attributes that are correlated with average computer use and that influence retirement. I use a number of strategies to assess the validity of the instruments, in light of these concerns.

• As discussed earlier, occupation and industry effects had a statistically insignificant impact when added to the OLS estimates along with the detailed HRS controls.

• While average computer use by occupation plays a key role in the first stage regression, average computer use by industry adds little explanatory power.[25] This suggests the possibility of including unrestricted industry effects in the main regression and instrumenting only with occupational computer use. The resulting computer use estimate rises slightly to 0.077 (0.041). The estimates still rise with age, and, for example, the estimate for ages 55–59 of 0.092 (0.062) is almost the same.

• Another strategy is to add more variables from the HRS. Several variables de-

[25]In the first stage, including only the occupational average yields an R^2 of 0.273; adding the industry average and the interaction of the occupation average with the industry average raises it to 0.288.

Table 11. Explaining Retirement.
(Instrumental Variables Regression Coefficients, Standard Errors in Parentheses)

	Dependent Variable: The Person Is Still Working, 1992 → 96		
Independent Variable	*IV-3*	*IV-4a*	*IV-4b*
Uses a Computer (Fitted)	0.047	0.071*	0.066*
	(0.031)	(0.037)	(0.036)
Education:			
High School	0.062**	0.061**	0.062**
	(0.021)	(0.020)	(0.020)
Some College	0.076**	0.072**	0.074**
	(0.024)	(0.024)	(0.024)
College +	0.102**	0.107**	0.109**
	(0.027)	(0.026)	(0.026)
Also Includes	Age, Demographic Characteristics	Age, Demographic and Job Characteristics	
Instruments		Average Computer Use	Average Computer Use, Change in Computer Use
	Dependent Variable: Same 1992 → 94		
Uses a Computer (Fitted)	0.040	0.033	0.027
	(0.027)	(0.031)	(0.031)
	Dependent Variable: Same 1994 → 96		
Uses a Computer (Fitted)	0.048*	0.069**	0.064**
	(0.029)	(0.033)	(0.033)

Sample: HRS. See Table 10 notes. IV-3 is the instrumented version of OLS-3 in Table 10, while IV-4a and IV-4b are instrumented versions of OLS-4, with different sets of instruments as reported in Table 9. Instruments for computer use: occupation and industry average computer use for prime-age workers. Estimated with the person-level analysis weights, Huber-White standard errors.

*Statistically significant at the .10 level; **at the .05 level.

tailing other job requirements—physical effort, intense concentration, dealing with people, high stress, and so on—do not have a statistically significant effect on retirement or reduce the explanatory power of computer use. The only additional variable that matters is an indicator for responsibility for pay and promotion decisions, asked of non—self-employed workers. Added to OLS-4, pay and promotion responsibility has an impact on retirement similar to that of computer use. Added to IV-4a, it lowers the computer use effect by about 10%, from 0.075 (0.039) to 0.066 (0.040), just statistically significant at the 90% level.[26]

• Outside sources may also yield information about occupation and industry characteristics. To this end, I assembled data on retirement rates from the late 1970s, before the 1981 launch of the personal computer.[27] Indicators of earlier retirement rates would kill the estimated computer use effect if they capture omitted job characteristics that persist today, especially since industry retirement patterns remain similar.[28]

[26]The estimated effect of the pay/promotion variable on retirement is 0.031 (0.017) in OLS and 0.025 (0.018) in IV.

[27]These measures are described in the appendix. I am grateful to Lawrence Katz for this suggestion. Adding average training rates from the January 1991 CPS did not affect the estimates either.

[28]The correlation coefficient between industry retirement rates in the 1990s and the late 1970s is 0.679. Occupational retirement rates are not closely related. The results are the same using retirement data from the early 1980s, which include occupation

When measures of earlier occupation and industry retirement rates are added to OLS-4, the coefficient on computer use is almost unchanged. When they are added to IV-4a, the coefficient is 0.057 (0.040), down from 0.071 (0.037). Hence, while part of the variation in average computer use could reflect other influences on retirement, the estimate remains large, though imprecisely measured.

Thus, after I introduce several measures of other job attributes, the computer use effects remain close to the original estimates, especially for ages 55–59. Though these estimates are not precise, the results suggest that computer use had an independent effect on retirement, raising the probability of continuing to work by up to 25–30% over a four-year period.

Conclusion

Rates of computer use were remarkably similar for all but the oldest workers observed in this study, suggesting that most workers acquired computer skills as needed—even when they had long been out of school. The oldest cohorts kept pace with the spread of computers at younger ages, and lagged only in jobs that computerized rapidly and recently. These patterns indicate that impending retirement, not age alone, influenced the responses of older workers to computerization and other technological changes.

In turn, changes in skill requirements may affect retirement plans. Computer users were 25% more likely than non-users to continue working between 1992 and 1996. One possible explanation is that computer users have valuable skills that lead them to delay retirement; another is that they already intend to retire later and thus find it worthwhile to acquire skills. I used an instrumental variables approach to sort out this interaction. I estimated the impact of computer use on retirement by predicting computer use with the average in a worker's occupation and industry, while controlling for many other characteristics of workers and their jobs that are potentially correlated with computer skills and retirement. The results indicate that computer use led directly to later retirement. The estimates are not very precise, but they imply that computer use raised the likelihood of continuing to work by up to 25–30%. These effects are strongest for workers in their late fifties.

It is important to learn more about the impact of new technologies on older workers. Policies designed to encourage later retirement might have limited success if older workers face pressure from technological change. On the other hand, future delays in retirement, perhaps resulting from rising life spans or changes in Social Security and private pensions, may induce older workers to invest in new skills as technologies evolve.

codes that are much simpler to match to present codes.

DATA APPENDIX

What did people use computers for?

The CPS computer use supplements since 1989 have asked workers what they use computers for. Respondents are allowed to choose any number of about two dozen possible tasks. I assigned the specific tasks to several broad categories that appear in Table 6: common applications (word processing, databases, spreadsheets, and calendar/scheduling); communication tasks (communication, electronic mail, and bulletin boards [1993 only]); accounting tasks (bookkeeping, inventory control, invoicing, and customer records and accounts [1997]); sales tasks (sales, marketing, and telemarketing [1993]); graphics tasks (graphics, design, desktop publishing, newsletters, and computer-assisted design); programming; analysis; learning tasks (learning to use the computer [1993], educational programs [1993], and instruction [1989]); games; other; and don't know (1989 and 1993 only).

Retirement patterns by occupation and industry in the 1970s

In the last section of the paper I include controls for retirement patterns by occupation and industry from a time period before computers were important. Since there are no longitudinal retirement data from the late 1970s, I calculated a measure of retirement patterns using data from the outgoing rotation groups of the March CPS of 1977–80 and, for comparison, 1983–84 and 1992–93. Until 1993, people were asked about their last occupation and industry if they were not working but had worked in the previous 5 years.

I used these data to construct a summary statistic for retirement by occupation and industry at ages 60–62. I chose these ages because about half of workers retire by age 62, while at older ages many people will have retired more than 5 years earlier; these missing data could cause selection bias if people in some jobs retire earlier on average.

The statistic I computed is the "work rate" for each occupation and industry: the proportion who are currently working, relative to the total number who work or used to work in the same occupation and industry in the previous 5 years. The resulting work rates range from 0.802 for managerial specialties to 0.606 for transport operators. Occupation coding changed substantially after 1982, so I also computed work rates for 1983–84, using occupation codes that are consistent with today's codes; the estimation results were unchanged. Consistent occupation and industry codes for 1970, 1980, and 1990 were helpfully provided by David Autor.

Additional variables from the HRS

Below are descriptions of the variables included in regressions OLS-4, IV-4a, and IV-4b. The HRS question number on which the variables are based appears in parentheses. Additional details and coefficient estimates are reported in Friedberg (2001).

Your age, relative to the usual retirement age in your job (F90). Dummies for: older than usual retirement age, same age, 1–2 years younger, 3+ years younger (omitted), usual age not reported.

Your age, relative to average age of usual retirement in your occupation (averaged over the sample using the person-level analysis weights). Same for your industry.

Pension plan and early retirement age (ERA) when benefits are first available, relative to your age (F39, F45, F48). Dummies: has a DB pension + age > ERA, DB pension + age = ERA, DB pension + age < ERA, DB pension + ERA not reported, DC pension only, no pension (omitted).

Health insurance (HI) coverage (R2–R15a, R8). Dummies: HI from current or former employer of you or spouse, HI from government, HI purchased privately, no HI, no HI information (omitted). Dummy: retiree HI from an employer.

Log hourly earnings. Hourly pay on the main job (F16d), if the person is paid by the hour. Otherwise, earnings on the main job divided by the product of usual hours per week and weeks worked last year (F16a, F30a, F8, F10).

Liquid net worth. The natural log of 5354. Dummy: liquid wealth = 0.

Expects to receive or receives Social Security (N46, N41). Dummy.

Hospitalization (B45 and B45a in wave 1, B29 and B29a in wave 2, E1 and E2 in the 1998 release of wave 3). Dummies: hospitalized once in 1991, hospitalized twice or more in 1991, not hospitalized in 1991 (omitted); same for 1992–94, 1994–96.

Education (A3, A3a, A3d). Dummies: no high school diploma or, if no answer, did not complete 12th grade (omitted); no college but has high school diploma or, if no answer, completed 12th grade; associate's degree or completed more than 12 years of schooling but has no degree; has a 4-year college degree or more.

Demographics (A10, 47, 48). Dummies: married in 1992 with a younger spouse; married with same age or older spouse; married and don't know spouse's age; not married (omitted). Dummies: female; female and married; male (omitted). Dummies: race is black; race is other nonwhite; female black; female other nonwhite; race is white (omitted).

Change in marital status (A10 in wave 1, A1 in wave 2, E256A in the 4/99 release of wave 3). Dummies: married in 1992 and not in 1994, female and married in 1992 and not in 1994; same for 1994–96.

Age (46).

Work: Working for pay (F2 in wave 1, FA2 in wave 2, G3 in wave 3).

Industry, occupation (F4, F5, F6).

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