WHICH WORKERS GAIN UPON ADOPTING A COMPUTER?

By

Cindy Zoghi and Sabrina Wulff Pabilonia
U.S. Bureau of Labor Statistics
April 2005

Prepared for
Conference on the Evolving Workplace,
Crowne Plaza Hotel, 101 Lyon Street, Ottawa
September 28-29, 2005

I. Introduction

According to Robert Solow, "you can see computers everywhere but in the productivity statistics." One possible reason for this is a lag between the introduction of computers and their efficient use, because workers must learn to use the new technology and to incorporate it into their daily tasks in ways that improve efficiency. Paul David (1990) describes a similar lag in productivity gains following the 1881 introduction of the electric motor: "its implementation on a wide scale required working out the details in the context of many kinds of new industrial facilties, in many different locales, thereby building up a cadre of experienced factory architects and electrical engineers familiar with the new approach to manufacturing."(p.358)

This idea of a lag between the introduction of computers and productivity gains is supported by news reports of organizations computerizing their operations. For example, the city of Tacoma found no gains in productivity fifteen months after implementation, with one worker describing the new system as "a system that doesn't work correctly, that can't adapt to the way we do business…We have this huge system and no one knows how to run it." (Sherman and Hagey 2005) In other cases, the effects of computerization are quickly evident. Within three years of the introduction of check imaging technology in a large bank, significant employment and wage changes had occurred (Autor, Levy and Murnane 2002).

This suggests not only that establishments may not see immediate gains from the introduction of computers, but also that the length of the lag may be affected by how quickly the diffusion occurs, how much computer experience and ability workers have and what tasks computers perform or complement. Bresnahan, Brynjolfsson, and Hitt

(2002), making a similar point, argue that there may be differential returns to computer use across workers, since managers and professionals with high cognitive skills are especially important for the implementation of new technologies. These workers are needed to transform organizations to take advantage of new technologies and use the information to better serve their customers. Bresnahan (1999) explains that computers are substitutes for low- and middle-skilled white collar workers because their tasks can be regularized and routinized, but the tasks of high-skilled white collar workers can not be. Similarly, Bartel and Lichtenberg (1987) argue that since highly educated workers have a comparative advantage in adjusting to new technologies, the introduction of new technologies should shift demand away from less educated workers toward higher educated workers. There is some evidence of these differences in cross-sectional studies by Krueger (1993) and Tashiro (2003).

Several recent studies have used individual fixed-effects to measure the return to computer adoption for the average worker while controlling for heterogeneity. Most of these studies find very small, or negligible, immediate returns. Using retrospective data on computer usage from the German Socio-Economic Panel (GSOEP), Haisken-DeNew and Schmidt (1999) find a return to computer adoption of only one percent. Using French employer-employee matched retrospective data on new technologies, Entorf and Kramarz (1997) and Entorf, Gollac, and Kramarz (1999) find that the return to computer use for new users is insignificantly different from zero, while employees with one to three years of prior experience with computers earn a statistically significant return of two percent. Recently, Pabilonia and Zoghi (2005) used an instrumental variables technique and found no return to computer use, but rather a return to computer experience, when considering both new users and more experienced users.

There are two sources of bias in a standard fixed-effects estimate. First, the effects are identified by those transitioning both into *and out of* computer use. To the extent that there are differences in the elasticity of wages with respect to these two types of changes (perhaps due to downward wage rigidity), the fixed-effects estimate does not measure the return to adoption. In addition, the effects are measured relative to those who do not have transitions, which include both those who have a computer in all periods and those who never have a computer. It is unclear how to interpret the effect of these transitions relative to such a heterogeneous group.

Finally, we expect that returns differ among worker groups, depending on their education and possession of skills that would facilitate their adoption of computers. Additionally, returns may differ depending on the pace of computer diffusion within the establishment. In some cases, adoption is wide-scale, affecting much of the establishment, while in other cases, workers adopt computers one at a time, given their relative productivity. Workers adopting under these different diffusion patterns would not necessarily obtain similar adoption returns.

In this paper, we use a panel of workers and their establishments surveyed in the 1999-2002 Canadian Workplace-Employee Survey (WES) to re-examine wage premiums for adopting a computer at work. The panel attribute allows us to observe transitions into computer use, and to control for worker characteristics that may affect selection into computer use. Comparable to other studies, we estimate an individual fixed-effects specification, which identifies effects through all workers who change their computer use status. We then extend the analysis in several directions. First, we restrict our sample to those workers for whom adopting a computer is possible: in other words, non-computer users in the first wave. This restriction allows us to isolate the return to adopting a computer relative to other workers, who could adopt but do not. Additionally, we measure the returns to adoption for specific subgroups of workers: by worker skills (education, occupation, and previous computer experience), by type of computer application used, and by type of diffusion pattern in the establishment. These separate analyses suggest that the small return observed for the average worker obscures a tremendous variation in the returns to adoption and suggests that for some groups of workers computers do immediately affect the productivity of the establishment.

In the next section, we provide some theoretical motivation to help explain why returns to computer adoption may differ for workers with varying skills and how computer experience may influence returns. In section III, we discuss the WES and present some descriptive statistics on computer users and adopters in Canada. In section IV, we present fixed-effects models of computer adoption and show that returns to computer adoption vary depending on the worker's occupation, education level, prior computer experience, type of computer application used, and extent of concurrent diffusion in the establishment. Section V concludes this paper.

II. Theoretical Motivation

In a model presented by Borghans and ter Weel (2003), output is produced by a worker performing two tasks, one that can be computerized and one that can not. If a computer is adopted, the total time to produce a unit of output should decrease, so that labor costs per unit of output decrease. This savings is offset, however, by computer costs, e.g. depreciation, operating costs, software applications, etc. Skill bias is introduced into their model by assuming that the amount of time a worker needs to complete each task is related to skill and also that the amount of time saved by computerization is related to skill, since carrying out the computerized task requires skill.

This yields a computer adoption threshold that depends on the wage savings and the computerization costs. Since wages are positively correlated with skill, adoption is more likely among workers with higher skill levels. Similarly, Weinberg (2004) finds that workers with higher relative productivity in computerized tasks are likely to adopt earlier, and that more workers adopt as time passes. This indicates that a mass of skilled workers will adopt new technology.

Such models imply that high wages will be correlated with computer adoption, but not necessarily that the high wages are a return to adoption; rather, the high wages affect the threshold and thereby cause adoption. In fact, Doms, Dunne and Troske (1997) find that firms paying high wages are more likely to adopt computers. This also explains the difference between large cross-sectional estimates of the return to computer use found by Krueger (1993) and the much smaller returns that are found when controlling for the worker's characteristics prior to adopting computers (see, for example Entorf, Gollac and Kramarz 1999).

While it may be true that high wages affect the probability of adoption in this model, there are nonetheless labor productivity gains as well. In many cases, initial returns will be small, as workers must learn the new technology before being able to operate it efficiently. Bartel and Lichtenberg (1987), Chun (2003), Helpman and Rangel

(1999), Caselli (1999) and Helpman and Trajtenberg (1996) discuss these short-term costs associated with adopting new technologies and argue that the size of these costs may depend on the education and skill of the workers adopting. If highly-skilled, highly educated workers and those with previous computer experience have a comparative advantage in learning and implementing new technologies, adoption costs will be lower for them than for unskilled, less-educated workers, and the demand for highly skilled workers will increase in the short-run. Therefore, certain types of workers are likely to see returns to computer adoption, even in the first year of adoption. In particular, highly skilled workers, workers with prior computer experience, and those whose computer tasks are easier to learn are likely to earn higher wages after adoption, even controlling for pre-adoption wages and characteristics.

It is unclear *ex ante* how the returns to adoption may differ when an organization adopts computers for the majority of its workforce. On the one hand, the establishment may receive discounts on the purchase price of computers. Borghans and ter Weel (2003) show that in this case it is the average wage of the workers that determines the threshold, so that adopters include many lower wage workers who would not otherwise use a computer. For these lower wage workers, the value of their saved time does not cover the implementation costs. This would result in smaller productivity gains after adoption than otherwise. In addition, discounted bulk pricing would permit the adoption of less valuable applications (Bresnahan 1999). On the other hand, there may be scale efficiencies in learning and implementation that would shorten the delay in increasing productivity, as well as complementary organizational changes that increase productivity

(Bresnahan 1999; Bresnahan, Brynjolfson & Hitt 2003). Thus, the effect of the diffusion pattern upon the returns to adoption is an empirical question.

III. Data

The data we use for this analysis come from the first four waves of the Canadian Workplace and Employee Survey (WES).[1] This survey was initially conducted in 1999. Establishments in the WES are followed each year, while employees are followed for only two years and then re-sampled. For our analysis, we use both currently available two-year panels of employees (1999-2000 and 2001-2002) with their matched employer information. The panel aspect of the data allows us to control for pre-adoption wages and observable and unobservable individual characteristics that might affect the propensity for computer adoption as well as wage increases.

Establishments were first selected from employers in Canada with paid employees in March of the survey year with the exception of the Yukon, Nunavut, and Northwest Territories and "employers operating in crop production and animal production; fishing, hunting, and trapping; private households, religious organizations and public administration" (Statistics Canada 2002, 23). At each establishment, a maximum of twenty-four paid employees were then randomly sampled from a list of employees. All employees were selected in establishments with fewer than four employees. In 1999, 6,322 employers and 23,540 employees were interviewed. In 2000, 20,167 of those employees were re-interviewed. In 2001, employees were re-sampled at continuing workplaces to start a new two-year employee panel, which consisted of 20,377 employees in 2001 and 16,813 in 2002.

[1] This data was used by remote access to Statistics Canada.

The WES is rich in questions concerning the use of technology by establishments and their employees. One of the central variables in our study is computer use by employees. Specifically, employees were asked "Do you use a computer in your job? Please exclude sales terminals, scanners, machine monitors, etc." Table 1 describes the proportion of workers who used a computer at work in 1999 and 2001, and the proportion of workers who subsequently adopted a computer in the following year.[2] Sixty-three percent of Canadian workers used a computer at work in 1999, and seven percent adopted computers between 1999 and 2000. The rates are similar for 2001 and 2002: 62 percent used a computer, and six percent adopted a computer.[3]

Skilled workers have the highest rates of computer use. Over 80 percent of workers with at least a bachelor's degree used computers in both periods. Rates for those with some college or a vocational degree are over 60 percent, while rates for those with a high school level degree or less are below 50 percent. However, computers do appear to be diffusing among these lower skilled workers; nearly nine percent of workers with less than a high school diploma had adopted computers by their second year in the sample. Adoption rates are necessarily lower for the more skilled groups where computers are already so prevalent.

Consistent with these patterns of use and adoption across skill groups, computer use is very high among managers and professional workers, well over 80 percent. In addition, computer use is prevalent among clerical and administrative workers (89

[2] Survey means and proportions throughout the paper have been weighted using employee weights.
[3] These proportions are comparatively larger than the 53% of U.S. workers who used a computer at work in 2001. This figure is the authors' calculation from the Current Population Survey Supplements (U.S. Bureau of Labor Statistics 2001). The percentage is comparatively lower than the 75% of U.K. workers who reported using a computer at work in 2000 in the National Child Development Study (Dolton and Makepeace 2004).

percent in 2001). Less than 20 percent of production workers used computers in either year, while over 40 percent of technical and sales workers used computers. Adoption was highest among technical, trade and sales workers.[4]

Table 1 confirms the theoretical prediction that high-wage workers will be most likely to adopt computers during the early stages of a technological innovation. The workers with the highest rates of computer use are those who are most likely to have high wages: managers, professionals and highly educated workers. In Table 2, we control for those initial high wages by measuring wage changes that occur between the first and second years of each panel. Wages are measured by the natural logarithm of the hourly wage. In the compensation section of the WES, employee respondents reported their wage or salary before taxes and other deductions in any frequency they preferred (e.g. hourly, daily, weekly, annually). They were also asked about additional variable pay earned from tips, commissions, bonuses, overtime pay, profit-sharing, productivity bonuses and piecework in the last twelve months. Statistics Canada derived hourly compensation by dividing wages plus additional compensation by the total reported hours.[5] In our analysis, we used their hourly compensation data as the measure of hourly wage.

On average, workers experience 3.4 percent wage growth between 1999 and 2000 and 4 percent growth between 2001 and 2002. Those who did not use a computer in either year had much lower growth, while adopters and those who used computers in both

---

[4] Appendix Table A1 shows the rates of computer use by other demographic characteristics. These relationships look fairly similar to those observed in other studies.

[5] Managers may be more likely to work unreported hours than other workers. Thus, hourly wages for this occupational group may be overestimated.

periods had higher wage growth. Workers who stopped using a computer by their second year experienced wage growth that was slightly less than the average worker.

The WES asks workers "considering all jobs you have held, how many years have you used a computer in a work environment?" We are thus able to distinguish those workers who adopted a computer but had prior computer experience acquired both on their current job and at other jobs from those who adopt a computer with no prior work-related computer experience. Table 2 does not suggest a clear pattern of wage growth differences between these two groups—in the second panel (2001-2002), the experienced workers have higher growth, while in the first panel (1999-2001), they have lower growth than those without experience.

We also analyze two groups of employees: those who report adopting a computer as part of a wide-scale implementation in the establishment, and other adopters. One way to make this distinction comes from the information on the employer survey on "how many employees at this location currently use computers as part of their normal working hours?" We measure the change in workplace computer usage between the two periods as a fraction of the total employment in the second year; establishments in the top quartile of this statistic are considered to have undergone a wide-scale implementation. A second measure comes from a question in the employer survey on whether "your workplace has implemented a major new software application and/or hardware installation…that would affect at least half of the users in the workplace?" These measures suggest that workers who adopt as part of a large implementation may have higher wage growth than those who do not. The drawback of the second measure, however, is that it combines software and hardware adoption, while this paper focuses on hardware adoption.

Table 2 also suggests that a full-sample fixed effects estimate of the return to computer adoption will yield results that are difficult to interpret. There does not appear to be a significant wage reduction from stopping computer use that would make it reasonable to combine transitions into and out of computer use. Nor is the reference group of non-transitioning workers homogeneous, since those who never use computers experience much slower wage growth than those who always use computer. For these reasons, we use a different estimation strategy, restricting our sample to those who do not use a computer in the first year of either panel.

IV. Estimation and Results

To measure the effect of adopting a computer on wages, we first estimate the following traditional fixed effects specification, combining the 1999-2000 and 2001-2002 panels:

$$\ln W_{it} = \alpha + \beta X_{it} + \gamma Comp_{it} + \delta_i + \varepsilon_{it} \qquad (1)$$

where W_{it} is individual *i*'s hourly wage rate at time *t*; X_{it} is a vector of observed characteristics of *i* at time *t*; $Comp_{it}$ is a dummy variable equal to one if *i* uses a computer at time *t*, and zero otherwise; δ_i is the non-time varying individual fixed-effect; α, β, and γ are parameters to be estimated; and ε_{it} is a stochastic disturbance term assumed to follow a normal distribution.

Many standard demographic variables included in wage regressions are time-invariant and thus do not appear in the fixed-effects estimation. X_{it} only includes those characteristics of the worker or the worker's establishment that vary between the two years. We include education, which does change for a number of workers. [6] Additionally, we include potential experience and its square[7], tenure squared, and binary variables for whether or not the worker speaks a different language at home than at work, is a part-time worker, is married, is married interacted with gender and is covered by a union coverage since these variable can change from year to year. The size of the establishment, in terms of number of employees, can increase or decrease between one year and the next. We also include a binary variable for whether or not the worker was recently promoted – sometime during either the first or second year – since a promotion may be correlated with both changes in computer use and changes in wages.[8]

Table 3 shows the results of this estimation. The first column uses the sample of workers present in both periods to estimate the model, resulting in a sample size of 70,066 worker-year observations with non-missing data. The return to computer use is 1.62 percent, which is comparable to the results by Entorf, Gollac and Kramarz (1999). We interpret this as the return to transitioning into or out of computer use relative to those who either never used computers or always used computers. To measure the return to adoption relative to not adopting, we restrict the sample to those who were not using computers in the first period. This restriction eliminates those who used a computer in both years as well as those who ceased using a computer. Even though our sample size is reduced to 24,392, we believe this is an appropriate restriction.[9] Identification comes from the 15.9 percent of workers who adopt computers in the second period. The second column of Table 3 shows that the average worker who adopts a computer experiences

---

[6] It is possible that some of this change is due to measurement error in one or both of the years.
[7] Potential experience changes because it is age-education-6.
[8] Appendix Table A2 shows the mean between-year changes in these variables in each panel.
[9] Zoghi & Pabilonia (2004) use a more flexible first-difference specification to separate the effects of ceasers and adopters and find similar returns to adoption.

3.31 percent higher wage growth in the first year of adoption than a similar worker who does not adopt.[10] We also include a wage indicator.[11]

To test whether there are differential returns to adopting by worker education, skill and the scale of implementation, we further divide the sample into several subgroups based on these criteria. In Table 4 we report the effect of adopting a computer on wage growth for each subsample. The patterns across education groups provide strong evidence that highly-skilled workers do see an immediate return to computer adoption, even after controlling for wages and demographic characteristics prior to adoption. Workers with an advanced degree have a statistically significant 15.7 percent higher wage growth in the year following adoption than comparable workers who do not adopt; premiums for those with a bachelor's degree are over six percent, and for those with some college or a vocational degree are nearly three percent. Less educated workers, those with only a high school degree or less, do not earn higher wages in the year they adopt compared to their counterparts who do not adopt.

The results across occupation groups show similar heterogeneity. The 6.9 percent premium for managers who adopt computers is much larger than that for all other occupations. Technical and trade workers are the only other workers who have higher wage growth (2.3 percent) following adoption than comparable workers who never use a computer.

---

[10] We also tried two alternative specifications. As a further test of whether we have adequately controlled for individual heterogeneity, we estimated an instrumental variables first-differenced model on the restricted sample. Results were essentially the same, and instruments were significant; however, a Wald test would not allow us to reject the hypothesis of independence of error terms in the model, thus indicating that the standard fixed-effects model was appropriate. In addition, we estimated a first-differenced model with establishment fixed-effects to make sure we adequately controlled for establishment heterogeneity. Results indicate a significant 3.9 percent return to computer adoption, a slightly stronger wage growth. Full results are available upon request from the authors.

[11] It is possible that there may be differences in wage growth between panels due to lower economic growth in 2001-2002 than 1999-2000 and not just due to sample differences.

These results show that education and skills affect whether a worker can increase their productivity by using a computer. Highly-skilled individuals are likely to learn more quickly and require less computer training in order to become more efficient.[12] Likewise, a worker who has previously used a computer on the job should adapt to using a computer on their current job more quickly than a worker without prior experience. In our sample, nearly 28 percent of those who were not using a computer in the first year of the survey had previous experience using a computer on a job. We therefore divide the sample into those with and without prior computer experience and estimate equation (1) for these samples. The results of these estimations are at the bottom of Table 4. A comparison of the models suggests that workers who adopt computers and have prior computer experience earn 1.5 percent higher wages than workers who have never used a computer at work. Pabilonia and Zoghi (2005) find this is true for all computer users, as well. This sample restriction results in very little variance for our analysis; as a result, the difference between the models is not statistically significant. We nevertheless take this as additional evidence that skilled workers do earn an immediate premium when adopting a computer.

Returns to adopting a computer may also differ in terms of how diffusion proceeds in the establishment: whether a majority of the workplace adopts computers simultaneously or workers adopt individually. We measure this in two ways: first, we examine whether the establishment had a large change in the number of computer users relative to the total employment, and then we determine whether the establishment recently had a major software or hardware implementation that affected a majority of

[12] Recently, Zoghi and Pabilonia (2004) find evidence suggesting that workers share training costs through sacrificed wages. Valletta (2004) also argues that computer training is important in explaining workers' wage profiles.

workers. The results of these separate estimations are at the bottom of Table 4. Again, the amount of variation to exploit in these models is low, so it is difficult to obtain statistically significant differences between the models. However, contrary to descriptive statistics, the return to adoption is a half to one percent larger for those workers who do not adopt as part of a wide-scale implementation. This may be due to the discounted cost of computers lowering the threshold for adoption, resulting in some workers who might be less productive adopting computers and lowering the average wage return. Alternatively, it may be a reflection of more time needed to effectively implement new computer systems as opposed to getting several more users hooked up to an existing computer network. According to Bresnahan, when firms install new computer systems, they "must invent new ways of organizing work, new job definitions, and new management structures." (1999, F398)

Another source of heterogeneity that may affect the returns to computer adoption stems from the different tasks that a worker performs using a computer. Autor, Levy and Murnane (2002) show that technology may complement a worker who performs problem solving tasks but substitute for a worker who performs repetitive tasks. If this is the case, then it may be important to look at more detailed questions of technology use. Employees were asked which software application they spent the most time using. While they were free to answer any specific application, the answers were then coded into one of fourteen aggregate categories of software. Table 5 shows the share of workers using each type of software as their main application in the first year of the panel and the share of workers adopting each type of software by the second year. Word processing and specialized office programs are the two most commonly used applications. Adoptions are highest for those two applications as well.

To estimate the return to adopting a new computer and using a particular software application, we estimate the following fixed-effects equation:

$$\ln W_{it} = \alpha + \beta X_{it} + \gamma_1 Soft_{1it} + \gamma_2 Soft_{2it} + \ldots \gamma_{14} Soft_{14it} + \delta_i + \varepsilon_{it} \qquad (2)$$

where all variables are defined as in equation (1), and $Soft_{jit}$ is an indicator variable that equals one if worker *i* used software *j* as her main application in time *t*. Since the sample is restricted to those workers who do not use a computer in the first year, $Soft_{jit}$ will be zero for all workers in year one and will change to one for any worker who both adopted a computer and also used *j* as her main application. As in equation (1), the excluded group contains those workers who do not adopt a computer.

Results of these estimations are in Table 6. The wage premium is the largest for those adopting computer-assisted engineering, desktop publishing, programming, and data analysis (14%, 11%, 7.2%, and 6.8% respectively) compared to non-adopters, although results are only statistically significant for computer-assisted engineering. The high wage premium on computer-assisted engineering is consistent with recent results by Dunne and Troske (2004), who find that manufacturing plants adopting technologies related to design and engineering tasks have faster employment growth and higher skilled workforces prior to adoption than non-adopting plants. All of these applications require critical thinking or problem-solving skills. However, the variation that allows identification of the coefficients in this model comes from individual workers who adopt a computer and a particular software application. The number of workers in each group is quite small, resulting in large standard errors. Adopters who use word processing, communications, specialized office, and database applications also earn significant wage premiums (6.1%, 4.9%, 3%, and 2.9% respectively). These applications are likely the primary application used by managers who we previously saw earned a high wage premium for using a computer. Thus while some of the estimates are quite noisy, there appear to be some differences in the wage premium depending upon the primary application adopted.[13]

V. Conclusion

In this paper, we show that a traditional fixed-effects model of wages with an indicator variable for computer use does not accurately measure the return to adoption. In fact, it measures the return to transitioning into or out of computer use relative to not making such a transition. As a result, the effect is averaged over workers who adopt a new computer, as well as over workers who stop using a computer. The reference group is likewise averaged over workers who have never used a computer as well as those who used a computer throughout the period. To obtain a more meaningful measure of the return to adoption, we restrict our sample to those workers who did not use a computer in the first period.

We use two panels of the Canadian Workplace and Employee Survey from 1999-2000 and 2001-2002 to estimate this fixed effects model. We find a much higher return to adoption for the average worker than has been previously estimated. In addition, we find that this return varies considerably across different types of workers and types of adoptions. Highly skilled workers, such as college graduates, white collar workers and

[13] We also estimated returns to computer-aided technologies and other technologies, but found they were not statistically different from zero.

workers with previous computer experience earn quite high premiums for computer adoption. We find weak evidence that workers who adopt a computer as part of a wide-scale implementation earn lower returns than those who adopt individually. Finally, returns vary depending upon what tasks the workers perform on a computer. Those adopting a computer for computer-assisted engineering, communications, data management and word processing earn significant returns, while those adopting for other tasks do not. Overall, there are many cases where workers do see an immediate gain from using computers, even in the first year following adoption.

References

Autor, David H.; Levy, Frank; and Murnane, Richard J. "Upstairs, Downstairs: Computer-Skill Complementarity and Computer-Labor Substitution on Two Floors of a Large Bank." *Industrial & Labor Relations Review 55(3) (2002):432-47.*

Bartel, Ann P., and Frank R. Lichtenberg. "The Comparative Advantage of Educated Workers in Implementing New Technology." *The Review of Economics and Statistics 69 (1) (1987): 1-11*.

Borghans, Lex, and Bas ter Weel. "The Diffusion of Computers and the Distribution of Wages." Unpublished Paper, Maastricht University, October 2003.

Bresnahan, Timothy. "Computerization and Wage Dispersion: An Analytical Reinterpretation." *Economic Journal* 109 (127) (1999): F390-415.

Bresnahan, Timothy; Brynjolfsson, Erik; and Hitt, Lorin M. "Information Technology, Workplace Organization, and the Demand for Skilled Labor: Firm-Level Evidence." *Quarterly Journal of Economics* 117 (2002): 339-76.

Caselli, Francesco. "Technological Revolutions." *The American Economic Review* 89 (1999): 78-102.

Chun, Hyunbae. "Information Technology and the Demand for Educated Workers: Disentangling the Impacts of Adoption Versus Use." *The Review of Economics and Statistics* 85 (2003): 1-8.

David, Paul A. "The Dynamo and the Computer: An Historical Perspective on the Modern Productivity Paradox." *The American Economic Review* 80 (1990): 355-361.

Dolton, Peter, and Gerry Makepeace. "Computer Use and Earnings in Britain." *The Economic Journal* 114 (2004): C117-C130.

Doms, Mark; Dunne, Tim; and Troske, Kenneth, R. "Workers, Wages, and Technology." *Quarterly Journal of Economics* 112 (1997): 253-90.

Dunne, Timothy, and Kenneth Troske. "Technology Adoption and Workforce Skill in U.S. Manufacturing Plants." *IZA Discussion Paper* No. 1427 (2004). Forthcoming *Scottish Journal of Economy*.

Entorf, Horst; Gollac, Michel; and Kramarz, Francis. "New Technologies, Wages, and Worker Selection." *Journal of Labor Economics* (1999): 464-91.

Entorf, Horst, and Francis Kramarz. "Does Unmeasured Ability Explain the Higher Wages of New Technology Workers?" *European Economic Review* 41 (1997): 1489-1510.

Haisken-DeNew, John P., and Christoph M. Schmidt. "Money for Nothing and Your Chips for Free? The Anatomy of the PC Wage Differential." *IZA Discussion Paper* 86 (1999).

Helpman, Elhanan, and Antonio Rangel. "Adjusting to a New Technology: Experience and Training." *NBER Working Paper* No. 6551. May 1998.

Helpman, Elhanan, and Manuel Trajtenberg. "Diffusion of General Purpose Technologies." *NBER Working Paper* No. 5773. September 1996.

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

Pabilonia, Sabrina, and Cindy Zoghi. "Returning to the Returns to Computer Use." Forthcoming *AEA Papers and Proceedings*, May 2005.

Sherman, Kris, and Jason Hagey. "New Computers Strain City's Wallet, Workers." *The News Tribune*, February 6, 2005.

Statistics Canada, Business and Labour Market Analysis Division & Labour Statistics Division. *Guide to the Analysis of Workplace and Employee Survey 2000, Version 2.1,* Ottawa, Ontario (2002).

Tashiro, Sanae. "The Diffusion of Computers and Wages in the U.S.: Occupation and Industry Analysis, 1984-2001." Unpublished paper, Claremont Graduate University, December 2003.

U.S Bureau of Labor Statistics/U.S. Census Bureau. *Current Population Survey Supplements*. September 2001.

Valletta, Robert G. "The Computer Evolution: Diffusion and Changing Returns in the U.S., 1984-2001." Manuscript, Federal Reserve Bank of San Francisco. 2004.

Weinberg, Bruce A. "Experience and Technology Adoption." *IZA Discussion Paper* No. 1051. March 2004.

Zoghi, Cindy, and Sabrina Pabilonia. "Which Workers Gain from Computer Use?" *BLS Working Paper* No. 373. June 2004.

Table 1. Proportion using computers and adopting, by education and occupation

	Using in 1999	Adopt by 2000	Using in 2001	Adopt by 2002
Full sample	.6251	.0665	.6225	.0578
Advanced degree	.9064	.0283	.8838	.0488
Bachelor's degree	.8279	.0456	.8847	.0340
Some college/vocational degree	.6246	.0691	.6596	.0585
High school graduate	.4542	.0759	.4585	.0587
Less than high school graduate	.3084	.0893	.2598	.0858
Managers	.8469	.0537	.8338	.0309
Professionals	.8531	.0478	.8763	.0443
Technical/trade	.4657	.0643	.4641	.0730
Marketing/sales	.4235	.0940	.4773	.0592
Clerical/administrative	.8617	.0340	.8889	.0258
Production/no trade	.1946	.0751	.1538	.0320
Number of observations	19,364		15,669	

Note: Proportions are weighted to account for survey design.

Table 2. Wage growth by computer use and transitions

	1999-2000	2001-2002
All workers	.0340	.0398
	(.0060)	(.0034)
	[19,364]	[15,669]
Never used computer	.0009	.0296
	(.0118)	(.0056)
	[5,740]	[4,607]
Always used computer	.0524	.0436
	(.0060)	(.0046)
	[11,895]	[9,742]
Adopted	.0341	.0612
	(.0458)	(.0149)
	[1,094]	[755]
Adopted with previous experience	-.0139	.0713
	(.0873)	(.0237)
	[461]	[383]
Adopted with no previous experience	.0774	.0507
	(.0336)	(.0178)
	[633]	[372]
Adopted in wide-scale implementation	.0723	.1055
(measured by change in computer users at	(.0539)	(.0438)
establishment as a fraction of total employment)	[241]	[128]
Adopted not in wide-scale implementation	.0237	.0495
(measured by change in computer users at	(.0562)	(.0146)
establishment as a fraction of total employment)	[853]	[627]
Adopted in wide-scale implementation	.0318	.0527
(measured by major new software/hardware	(.0256)	(.0254)
installation in previous year)	[346]	[161]
Adopted not in wide-scale implementation	.0016	.0651
(measured by major new software/hardware	(.0710)	(.0183)
installation in previous year)	[661]	[562]
Ceased using computer	.0284	.0368
	(.0247)	(.0146)
	[635]	[565]

Notes: Means are weighted to account for survey design. Standard errors in parentheses. Number of observations in brackets.

Table 3. Fixed effects wage regression, full sample and restricted sample

	Full sample	First year non-users
Computer Use	.0162***	.0331***
	(.0045)	(.0067)
Education	.0256***	.0223***
	(.0026)	(.0046)
Potential experience	.0383***	.0245***
	(.0031)	(.0055)
Potential experience^2	-.0240***	-.0034
	(.0045)	(.0072)
Home language not work language	-.0025	-.0078
	(.0064)	(.0107)
Part-time worker	.0692***	.0452***
	(.0052)	(.0084)
Married	.0425***	.0574***
	(.0080)	(.0125)
Married*female	-.0201*	-.0001
	(.0119)	(.0230)
Union member	.0482***	.0643***
	(.0061)	(.0095)
Recently promoted	.0292***	.0247***
	(.0032)	(.0063)
Ln (establishment size)	.0149***	.0159***
	(.0030)	(.0054)
Tenure^2	.0028	.0044
	(.0034)	(.0064)
1999-2000 panel	.0056**	-.0173***
	(.0027)	(.0049)
Number of observations	70,066	24,392
R-squared	.0684	.0711

Notes: Standard errors are in parentheses. The sample is restricted to those employers who responded to the survey in both years and remained with the same employer. Significance levels: *** = p<.01; ** = p<.05; * = p<.10.

Table 4. Returns to adopting computers for select groups of workers

	First year non-users
All workers	.0331***
[N=24,392]	(.0067)
Advanced degree	.1569**
[N=326]	(.0635)
Bachelor's degree	.0673***
[N=1,016]	(.0310)
Some college/vocational	.0299***
[N=11,762]	(.0095)
High school degree	.0200
[N=5.482]	(.0115)
No high school degree	.0114
[N=5,806]	(.0173)
Managers	.0694**
[N=918]	(.0335)
Professionals	.0030
[N=1,054]	(.0257)
Tech/trade	.0233***
[N=15,562]	(.0084)
Marketing/sales	.0136
[N=892]	(.0358)
Clerical/admin.	.0059
[N=1,148]	(.0276)
Production/no trade	.0214
[N=3,376]	(.0250)
With Previous Computer Experience [N=5,982]	.0402***
	(.0116)
With no previous computer experience [N=18,410]	.0258***
	(.0087)
Establishment had wide-scale implementation (change in computer users as fraction of total employment) [N=4,232]	.0288*
	(.0153)
Establishment did not have wide-scale implementation (change in computer users as fraction of total employment) [N=20,160]	.0345***
	(.0075)
Establishment had wide-scale implementation (new software/hardware) [N=6,145]	.0238
	(.0226)
Establishment did not have wide-scale implementation (new software/hardware) [N=16,381]	.0334***
	(.0090)

Notes: Standard errors in parentheses. The sample is restricted to employees who responded to the survey in both years and remained with the same employer. Regressions also include years of education, potential experience and its square, speaks different language at work, part-time status, marital status, gender interacted with marital status, is covered by a union, the natural log of establishment size, tenure squared, a recent promotion, and a wave indicator. Significance levels: *** = p<.01; ** = p<.05; * = p<.10.

Table 5. Proportion using and adopting computers, by primary software type

	Use in 1999	Adopt by 2000	Use in 2001	Adopt by 2002
Word processing	.1487	.0116	.1237	.0081
Specialized office	.1474	.0189	.1632	.0153
Databases	.0606	.0084	.0758	.0059
Spreadsheets	.0599	.0063	.0603	.0056
Communications	.0454	.0043	.0580	.0078
Expert systems	.0157	.0015	.0136	.0009
Management applications	.0132	.0023	.0209	.0022
Graphics	.0092	.0007	.0124	.0011
Computer-assisted design	.0070	.0007	.0100	.0005
Programming	.0067	.0009	.0073	.0002
Desktop publishing	.0058	.0002	.0063	.0001
Data analysis	.0049	.0003	.0055	.0023
Computer-assisted engineering	.0026	.0003	.0025	.0006
Other	.0981	.0102	.0631	.0073
Number of observations	19,364		15,669	

Note: All proportions are weighted to account for survey design. Communications includes e-mail and web browsers.

Table 6. Returns to adopting specific software applications

	Adoption return
Word processing	.0612***
	(.0154)
Specialized office	.0300**
	(.0128)
Databases	.0292*
	(.0177)
Spreadsheets	.0135
	(.0196)
Communications	.0489***
	(.0186)
Expert systems	.0655
	(.0435)
Management applications	.0292
	(.0344)
Graphics	.0418
	(.0474)
Computer-assisted design	.0472
	(.0528)
Programming	.0724
	(.0590)
Desktop publishing	.1092
	(.0762)
Data analysis	.0677
	(.0640)
Computer-assisted engineering	.1367*
	(.0795)
Other	-.0060
	(.0161)
Number of observations	24,392
R-squared	.0721

Notes: Standard errors in parentheses. The sample is restricted to employees who responded to the survey in both years and remained with the same employer. Regressions also include years of education, potential experience and its square, speaks different language at work, part-time status, marital status, gender interacted with marital status, is covered by a union, the natural log of establishment size, tenure squared, a recent promotion, and a wave indicator. Significance levels: *** = p<.01; ** = p<.05; * = p<.10.

Table A1. Proportion of computer use, by demographics

	1999	2000	2001	2002
All workers	.6251	.6452	.6225	.6323
Male	.5937	.6090	.5861	.6073
Female	.6535	.6780	.6572	.6569
Married	.6542	.6690	.6585	.6677
Not married	.5843	.6123	.5754	.5847
European background	.6081	.6303	.5965	.6093
Not European background	.6277	.6474	.6271	.6364
Ages 18-24	.4472	.4535	.4483	.4283
Ages 25-39	.6755	.6802	.6517	.6668
Ages 40-54	.6452	.6694	.6648	.6620
Ages 55+	.5096	.5650	.5167	.5824
Home language not work language	.5442	.5681	.5295	.5449
Home language is work language	.6320	.6522	.6332	.6422
Union	.5273	.5468	.5869	.5906
Non-union	.6655	.6853	.6374	.6497
Part-time worker	.4572	.4982	.4317	.4700
Full-time worker	.6683	.6785	.6721	.6721
Workplace ≤ 20 employees	.5860	.6104	.5465	.5610
Workplace 20-99 employees	.5789	.5938	.5752	.6324
Workplace 100-499 employees	.6115	.6124	.5997	.5710
Workplace 500+ employees	.7500	.7417	.7703	.7768
Number of observations	19,364		15,669	

Note: Proportions are weighted to account for survey design.

Table A2. Means of differenced variables.

	Full Sample		First year non-users	
	1999-2000	2001-2002	1999-2000	2001-2002
Δ ln(wage)	.0340	.0398	.0067	.0344
	(.0060)	(.0034)	(.0126)	(.0052)
Δ computer use	.0247	.0149	.1752	.1510
Δ years education	-.0520	.0884	.0662	.1399
	(.0168)	(.0136)	(.0284)	(.0321)
Δ (potential experience)	1.0520	.9116	.9338	.8602
	(.0168)	(.0136)	(.0284)	(.0321)
Δ (potential experience^2)	.3900	.3999	.3382	.4067
	(.0090)	(.0049)	(.0166)	(.0099)
Δ home lang. not work lang.	.0060	-.0016	.0074	-.0001
Δ part-time worker	-.0235	-.0099	-.0352	-.0278
Δ married	.0044	.0123	.0018	.0036
Δ married*female	-.0017	.0061	-.0065	-.0044
Δ union	.0052	.0102	.0117	.0150
Δ establishment size	-.0529	-.0159	-.0417	-.0181
	(.0065)	(.0058)	(.0106)	(.0108)
Δ (tenure^2)	.1281	.1454	.1327	.1209
	(.0119)	(.0055)	(.0078)	(.0111)
Number of observations	19,364	15,669	6,834	5,362

Notes: Means are weighted to account for survey design. Standard errors in parentheses.