Computerization and Wage Dispersion:

An Analytical Reinterpretation

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Preliminary and Incomplete
For Presentation at the NBER Summer Institute, August 4, 1997
Comments Welcome

Abstract

The United States has recently seen a dramatic rise in income inequality, all the more surprising because the long term trend had been toward equality. This paper examines one of the leading explanations; computerization in the workplace. I offer a theory of computers' impact on white-collar work which goes far toward explaining the timing, form, and locus of recent labor market changes. The theory looks at the bureaucratic and organizational applications of computers that have been first, largest, and most influential. They have two effects on firms' demand for labor at different skill levels. Computer decisionmaking has been a substitute for human decisionmaking over a limited range of tasks. Low- and middle-skill white collar work has been the most affected. Substitution of computers for high-skill workers has been quite limited. The rising demand for more highly skilled workers is driven by broad changes in the economics of the firm with many causes including computerization. While this theory is in agreement with many recent analyses pointing to computers, the specifics are quite different. Complementarities between computer use and individual workers' skills are not an important component of change. This very different view of the mechanisms of skill biased technical change has new implications for understanding labor markets over the last 25 years, for the policy debate, and for predicting the future evolution of labor demand.

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* Professor of Economics, Stanford University. I thank the Alfred P. Sloan Foundation for its generous support of the Stanford Computer Industry Project and the Stanford Center for Economics Policy Research for supporting the Employment and Growth in the New Economy initiative. Ron Borzekowski, Mike Mazzeo, Natalia Duncan, Anne Royalty and Fei Ye have offered very welcome help and comments, and seminar comments at SCIP and from the CEPR advisory board have been very useful.

1. Introduction

The distribution of wages and earnings has been spreading out in the United States for about a quarter of a century.[1] The wages and earnings of the well-off have been rising much more rapidly than those of low and middle income workers. An impressive body of empirical studies shows that the proximate cause has been a shift in the demand for labor.[2] Employers' demand has shifted from low- and middle-wage occupations and skills toward highly-rewarded jobs and tasks, those requiring exceptional talent, training, autonomy, or management ability. Supply appears to have been inelastic in the relevant run, so that the demand shift has played out as changes in relative wages. The distribution has spread out broadly, with high wages rising relative to median wages, which in turn rose relative to low wages. Underneath this general spread lie some specific trends. The premium paid for cognitive skills, as measured by educational attainment, has risen. It has also twisted, with an increase only for highly-educated workers. The premia for other skills have increased as well. The total effect has been large; the gap between wages at the 75th percentile of the distribution and the 25th has increased by nearly 50 percentage points.[3]

Pinpointing the causes of the labor demand shift has proved difficult. Quantitative assessments of other explanations shows that skill biased technical change (SBΔT) must be an important part of the story.[4] Since the largest technological event of the relevant period is a massive investment in information and communications technology (ICT), many observers have looked to the workplace impacts of computers and other ICT. Much of this analysis has taken SBΔT to be a residual, as we so often take all technical change. The residual analysis is convincing but incomplete. Autor, Katz and Krueger (1997), for example, convincingly show that the spread out in wage distributions is largest in the most ICT-intensive industries, primarily in services. This leaves us, unfortunately, without a clear understanding of the means by which new technology has been changing labor markets, whether the trend to inequality is likely to continue or be reversed, or the appropriate policy response.

The purpose of this paper is to offer a new theory of workplace computerization, specific enough to support causal, predictive, and policy analysis. The theory has three main ideas. First, the largest direct impact of ICT has been the substitution of machine decisionmaking for human decisionmaking in low- and medium-skilled white collar work. ICT has not been substitutable for high levels of human cognitive skill in highly-rewarded tasks and occupations. This limited substitution is at the heart of the SBΔT embodied in

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[1] See Karoly (1996), Gottschalk (1997) and the sources cited there.

[2] See Autor, Katz and Krueger (1997) for a summary of this evidence, a bibliography, and an interesting supply-demand framework.

[3] Murphy and Welch (1993) show percentiles of the wage distribution of prime-age males: the interquartile range has increased from about 1.75 to 1 to about 2.25 to 1. See Figure 1, below. More extreme percentiles have moved even farther from the median.

[4] Such forces as changing conditions of domestic and international competition, immigration, etc. while obviously relevant, are far too small to provide a the entire explanation. See Krugman and Lawrence (1993). But see Borjas and Ramey (1994) for the countervailing view.

ICT. Second, the strategic use of ICT has raised the demand for highly-skilled workers. The mechanism for this increase in demand does not arise through managers and professionals literally using a computer. Instead, ICT use changes the organization of production at the firm, industry, and even multi-industry level. This leads to an organizational complementarity between ICT and highly-skilled workers. Third, these organizational changes increase the demand for many skills, not just the cognitive ones learned in school. Noncognitive skills with rising demand include interpersonal and management ones, autonomy, and judgment. All three of these ideas are well supported in the analytical literature on the uses of computing. They are also very useful in understanding the timing, form, and locus of recent labor market changes.

In putting this theory forward I am attempting to save the general idea that ICT has had a great deal to do with wage dispersion from the failure of a specific theory of how it might have done so. Reich (1994) and others see wage premia for "symbolic analysts" or "knowledge workers" as related to the personal computer (PC) revolution. Enough attention has now been focused on this theory that it has become a standard. It is a theory of complementarity between computers and the human capital of computer users. Computerization makes individual workers' work more analytical, raising the return to cognitive skills and schooling for computer users. The skill bias arises from the shift out of the demand curve for highly cognitively skilled labor as the price of computing power, a complement in production, falls. Initially, this theory seemed promising, as cognitively skilled knowledge workers using PCs were shown to earn higher wages.[5] More recent evidence has shown that the PC revolution clearly comes too late to explain the labor market demand shift, and that high-wage jobs tend to draw PCs more than PCs cause high productivity.[6] Many observers now doubt that there is any important SBΔT associated with ICT.[7] This is an error of logic; that one specific version fails does not mean the entire class of theories is wrong. It is particularly dangerous to draw this conclusion given that the standard theory was formed without any analysis of the uses of computers.

1.1. Computers' Impact on the Labor Market

Computer business systems change white collar work. They change it by organizing, routinizing and regularizing tasks that people- and paper-based systems did more intuitively but more haphazardly. In the service sectors, and in the white collar activities of the goods sectors, they also change work by changing the nature of the firm's output. Computer-based production leads higher levels of service or even whole new (service) products. The labor-demand impact comes at the firm level, as computer business systems form the modern production process for many service industries (and for the service functions of other industries.) As computers have grown cheaper, and especially as computer networking has improved, computer-based production has spread more and more widely through white-collar work.

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[5] See Krueger (1993) and See also Wolff (1996) for measures of the skill attainment of the labor force and models of skill demand.

[6] See the work of Dinardo and Piscke (1997) and a summary of the whole literature in Autor, Katz and Krueger (1997).

[7] See, for example, Howell (1994) who writes of a "skills myth."

1.1.1. Limited Substitution of Computer for Human Decisionmaking

Anything which raises the demand for highly-skilled labor <u>relative</u> to that of less-skilled labor is a candidate SBΔT.[8] Computer business systems, from the 1960s, have involved the regularization and routinization of white-collar tasks. Simple, repetitive tasks are far more amenable to regularization and routinization than more complex and idiosyncratic ones. The result has been the systematic substitution of computer decisionmaking for human decisionmaking in clerical (and similar bureaucratic) work. Decisions that were once reached by humans in a paper- and people-based system are now reached by software. The scope of this substitution has been limited. Simple decisions, closely related to individual transactions or other operational actions, have been amenable to computerization. Such decisions have been regularized, routinized, and standardized, and the knowledge about how to reach such decisions has moved from the heads of clerks to the computer system. In this way, much routine white-collar work has been industrialized, and the same kinds of technical change processes that have long been lowering demand for blue collar workers in factories now lower demand for modestly-skilled white collar workers in bureaucracies. More complex and cognitively demanding work, such as that of managers, professionals, and technical workers, has proved remarkably difficult to automate with computers. Computer automation of white collar work has been correspondingly limited in its scope, affecting demand for clerks and expediters far more than for managers and professionals.

This <u>limited substitution</u> story is at the heart of computer SBΔT -- computers have been substituted first and foremost for the kinds of human capital whose relative wage is falling. This is strikingly obvious but has been equally strikingly absent from the discussion. The limited substitution theory has specific implications for aggregate labor markets. First, it has timing implications: we should look for SBΔT in connection with the computerization of bureaucracies starting in the late 1950s and accelerating through the 1960s and 1970s. Second, it has sectoral and occupational implications: supply substitution aside, the largest impacts should be in the most computer-related businesses (e.g., banking) and occupations (e.g., clerk.)[9] Third, the limited substitution theory suggests a particular pattern in the demand shift defined by the limit to substitutability. The demand shift should affect all kinds of work below this cutoff, and miss all kinds of work above it. This may explain the "twist" in the measured return to cognitive skills, as the relative wages of college- and better-educated workers have risen, while the relative wages of workers with some college, high school, or less, seem to have changed little.

1.1.2. Organizational Structure Changes at Firm Level

To complete such a theory, one needs to explain the rapidly rising real wages of more highly skilled workers. A simple explanation could come from rising real

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[8] As Griliches (1969) points out, any technical change embodied in capital that shifts the relative demand for workers of different skill levels in the aggregate is SBΔT.

[9] Supply substitution perhaps should not be left aside. The prediction implicitly assumes that labor supply to an particular industry or occupation is upward sloping (fine) but also assumes away any general-equilibrium effects in the markets for many different types of workers (less fine).

capital/labor ratios, driven by rapid and general embodied technical change.[10] From a purely logical perspective, that would offer a complete theory of SBΔT; demand for labor is rising in general because of the capital and technology boom, while demand for lower skilled labor relative to higher is falling due to particular features of the technology embodied in the capital.

The analysis of business computer systems leads also to a theory of their complementarity with highly skilled people. The analytical literature on business computer systems emphasizes their complementarity with changes in organization and with new products. It also emphasizes the cognitive difficulty of inventing new business computer systems.[11]

Effective use of computer systems involves a great deal of invention by the using firms. Firms do not simply install computers that automatically run effective business systems. Though computers are substitutable for clerks, the substitution does not work simply by removing the people and installing the computers. Instead, to gain from computers' capabilities, using firms must invent new ways of organizing work, new job definitions, and new hierarchies and management structures. Adding more complexity, the most computer-intensive businesses typically use computers for improved customer service and as the basis for new and improved services. Computers are themselves a general purpose tool that offer nearly a blank slate to using companies in the form of a new set of possible production processes. Technical progress in computers themselves constantly shifts the theoretical production possibility frontier out. Invention of the new products those processes will deliver and of the human side of the delivery mechanism are very difficult tasks.

These well-understood facts of computer use have powerful but still poorly-understood implications for the demand for skills. Computerized businesses are more routinized and more controllable than are people- and paper-based ones. This raises the demand for two very different kinds of skilled labor. First, it calls for technical specialists in user companies as well as in supplier companies. Second, it calls for managers who can think of ways to take advantage of the new production processes offered by computing. This calls for new cognitive skills, having a deep understanding of one's own organization and one's customers' needs.[12] This raises the demand for high levels of cognitive skills in

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[10] See Gordon (1990) for careful work on the size of the real capital stock taking into account technology and quality improvements in capital goods. Gordon concludes that K/Q and K/L have been rising. Other analysts have suggested that the real stock of computers is not growing this rapidly because technical progress leads to rapid economic depreciation. For purposes of examining labor market impacts, it seems right <u>not</u> to write down the older computers when technical progress occurs. It is the technical progress embodied in ICT capital, not the capital itself, we are concerned with.

[11] See Barras (1990), Bresnahan & Saloner (1996), Bresnahan and Greenstein (1996), Brynjolfsson (1994), and Friedman and Cornford (1989).

[12] Bartel and Lichtenberg (1987) suggest that high levels of cognitive skills may be particularly important in creating and adapting to change, notably in implementing new technology. The managerial side of computer-based production processes is an excellent example of this story.

managers and professionals. It also calls, as we shall see, for new levels of interpersonal skills at a wide variety of junctures in organizations.

There are two reasons to state this computer systems in organizations theory carefully, advancing over earlier ones which simply counted up all ICT investment or which focus on the PC. The first is positive. The theory explains the timing, occupational impact, industrial impact, and skills impact well. It explains the twist in the return to cognitive skills as measured by education, and it explains the new return to important noncognitive skills as well. It can be made to square with the technological history far better than the PC theory. It lacks the difficult problem of causal interpretation that the PC theory has had to deal with. In short, it appears to work well with the main stylized facts of the recent labor market.

A second reason to advance a detailed and specific theory is the better insight it gives us into the structure of the labor market changes occurring as a result of technical change. Here there are at least two main points to make. First, ICT technical change has not been a unitary force, always having the same sorts of impacts on labor markets. We are in an era of renewed interest in organizational and interorganizational computing, fueled by advances in computer networking technology. We are also in an era in which organizational computing is taking on some of the aspects of the PC, such as ease-of-use and flexibility. This paper will finish with a series of speculations about the future direction of workplace change related to information technology.

2. The Labor Demand Shifts to Be Explained

Empirical studies have shown that changes in relative wages involve, among other causes, unexplained changes in the demand for a variety of skills. This section reviews the findings of the two principal empirical literatures on this point. . The two literatures take a somewhat different tack on how to make the concept of "skill" operational. This richness means that this section can list several distinct labor-demand findings which any theory of skill biased technical change should explain

A wide variety of studies have examined individual worker wage equations.[13] Based on large data sets, such as the CPS, these studies predict wages with both observables -- education and experience -- and unobservables -- the residual in the wage equation. The observables are interpreted as proxies for skills. Changes in their coefficients over time are interpreted as changes in the prices of those skills. When the distribution of the residual spreads out, it is interpreted as an increase in the price of an unobserved skill. The most recent of these studies have used sophisticated analysis to decompose changes in skill prices into those caused by shifts in skill supply and skill demand.

It is clear that labor market equilibrium involves the setting of prices for several different skills. Juhn, Murphy and Pierce (1993) plot the prices of the skills proxied by education, experience, and the residual. While all three have risen over the long haul, they have not moved in lockstep. For example, the supply shift associated with the entry of the

[13] Surveyed in AKK (1997) and in Gottschalk (1997). I rely on Juhn, Murphy and Pierce (1993), Bound and Johnson (1992) and Murphy and Welch (1993). and especially AKK (1997) for much of what follows.

baby boom into the labor market raised the relative price of experience (many young people in the labor force) and lowered the relative price of education (many of the young people entered with education.)[14] For present purposes, the point is that any theory of SBΔT must explain separate biases in favor of several different skills.

The greatest analytical attention has been placed on education. It leads to two distinct findings:

F1 Cognitive Skills: The demand for more highly educated workers has been rising faster than that for less educated workers throughout the postwar era, so the measured return to education has risen.

F2 Twist: The return to education schedule has twisted. The relative wages of high-school and less-than-high-school educated workers have stayed constant, while the relative wages of more highly educated workers have risen.

The other two skill prices, experience and residual, measured in this framework are also rising, each as rapidly as the education one. This leads to only one more empirical finding, however:

F3 Experience: The demand for more experienced workers relative to less experienced workers has been rising more rapidly than the supply.

The "residual" premium or unobserved skill premium is growing as well. Yet it is not linked to any phenomena which a theory might predict. In this framework we can only conclude that there is a third, priced, attribute of labor and speculate about what it might have been.

Another body of empirical literature classifies skills differently, using the skill contents of different occupations. Based on sources like the dictionary of occupational titles, these studies look at the detailed skill requirements of jobs rather than of persons. The studies also examine the skill levels of the average person in an industry/occupation cell. One categorization of skills is into categories such as cognitive skills, motor skills, and interactive skills (such as those involved in supervising or being supervised.)[15]

The first finding is confirmatory of F1. The demand for cognitive skills has been rising over time. This finding is essentially the same whether cognitive skills are measured by education or more directly by test scores.

The second result in this literature is that the demand for motor skills is declining secularly. Blue-collar labor-saving in the goods-producing industries is an ongoing technical change process[16] It is unlikely that computerization marks an important shift in

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[14] See Murphy and Welch. (1993) Autor, Katz and Krueger (1997).and Bound and Johnson (1992) for a variety of skill supply/demand treatments.

[15] Howell and Wolff (1991) define the three types of skills: "cognitive skills- the level of cognitive (analytical reasoning) and diagnostic (synthetic reasoning) skills required; interactive skills - the relative authority, autonomy, and degree of responsibility (for people and things) required on the job; and motor skills- the various physical and manipulative requirements of work." p. 488. Obviously, these are still broad general worker capabilities rather than the skills associate with a particular job.

[16] There has been a long term decline in the demand for blue collar workers, and a declining share of employment in the industries, such as manufacturing, which use them. Johnson and Stafford, (1996).

this process.[17] Accordingly, I do not associate this empirical fact with a finding for the theory to explain.

The third finding in this literature, and the fourth overall finding for the theory to explain, relates to the interactive or “people” skills component.

F4 People Skills: The demand for workers with interactive skills has been rising more rapidly than the supply.

This finding applies to both workers in highly-paid and workers in lesser-paid occupations. It applies to workers whose jobs have, and do not have, high cognitive skills content.

The literatures have, in general, done a better job of carefully describing the supply and demand of cognitive skills than of other skills.

Both literatures also address issues of the timing and of the industrial composition of the demand shift. There is a long-term trend toward both higher demand for skilled workers and higher supply.[18] Because of the large transitory changes in labor supply associated in the 1970s, it is difficult to date the beginning of the current supply/demand shift. Because of the general macroeconomic noise of the 1970s and early 1980s, it is quite difficult to time the highest rate of changes in demand relative to supply down to half-decades.[19] The following finding about the secular (i.e. ignoring the ‘70’s blip) trend appears to be very solid, however:

F5 Timing: The demand for workers embodying these skills began to outstrip the supply in the late 1960s or possibly the early 1970s. A secular excess of the growth rate of demand over supply continues to the present day.

Finally, while there are some controversial aspects of the role of variety across industries,[20] there is also a very clear finding. The computer-intensive industries in

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[17] That technical change process was quite possibly augmented by improved control and automation by computer over the last several decades -- just as it has been augmented by a large number of advances in science and engineering more generally.

[18] See Goldin and Katz (1996a, b) for historical evidence focused on the entire 20th century.

[19] The issue is that supply shifts move the timing of relative wage movements vs. the underlying shift in the demand for labor. See Karoly, (1996) and Autor, Katz and Krueger, (1997) .

[20] The controversy is over how important composition effects have been in the demand shift. Some authors find that only within-industry demand shifts matter, while others find the secular shift from goods producing to service industries an important component. I have not yet come to understand the difference. It may be related to dependent variable. Scholars who look at wage dispersion tend to find that industry composition effects are not an important part of it. That is, only around 19% of the wage inequality can be attributed to changing industry shares. The remainder of the dispersion is attributed to within sector and inter industry shifts: Karoly (1993), Autor, Katz and Krueger, (1997). Also, there was a shift favoring more skilled workers in industries such as manufacturing which were previously dominated by less skilled workers. (Johnson and Stafford, 1996).

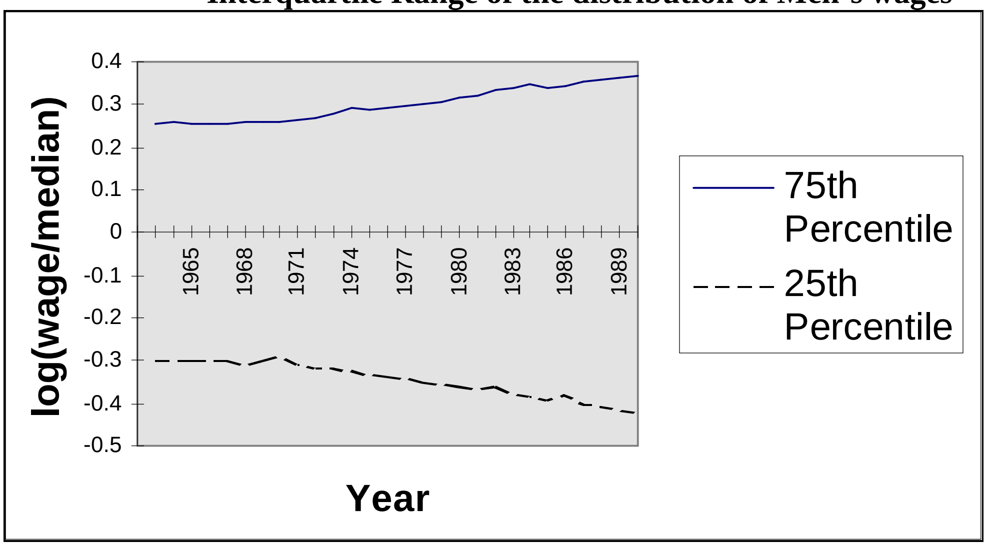
services, especially financial services, have seen the demand shift earlier (Wolff (1996)) and to a larger extent (AKK (1997)) than other industries.[21] Accordingly, we have

F6 Industry: The demand shift for skills is more marked in the more computer intensive industries.

The contribution of all these forces to wage dispersion has resulted in a general spreadout across the entire range of workers. For both men and women, blacks and whites, the nth percentile of the wage distribution is increasing faster over time than the mth if m<n. real wages and salaries in the upper parts of the income distribution are rising rapidly and that they are rising more rapidly than other wages and salaries.[22] The wages of highly paid workers have been rising rapidly in real terms, not just relative to less skilled workers. Whether the real wages of less-compensated people have been falling is more difficult to determine. Gottschalk (1997) reports, in his Figure 2, that the bottom 80% (!) of the distribution of men's wages fell in real terms from 1973 to 1994. A revised CPI, along the lines suggested by the Boskin commission, would reduce this proportion dramatically.

Figure 1

Interquartile Range of the distribution of Men's wages



The spread out in wage distributions is not at all small. Figure 1, reproduced from Murphy and Welch (1993), shows the interquartile range of men's wages over two and a half decades. Note the dramatic shift of the median man's wages up relative to the bottom quartile, and in turn of the upper quartile relative to the median. While our purposes in this paper are to examine the labor-demand consequences of this, an interesting literature is examining its implications for the distribution of income and related matters. There

[21] Although the portion of high skilled manufacturing workers increased from the 1970's to the 1980's, "the large acceleration in within sector skill-upgrading occurs from the 1960's to the 1970's outside of manufacturing." (Autor, Katz and Krueger, 1997).

[22] A third phenomenon, falling real wages for a wide variety of workers, depends on the deflator used in the calculation.

are some things about these changes which should perhaps become **F0 basics** as a finding. The clearest of these is that there is no repackaging of labor skills, or, in the language of another field, that human capital is not a scalar concept. The market treats distinct bundles of skills as different commodities that are priced distinctly. Thus, there is no (the movements in relative prices over time tell us) way to combine a number of high school graduates into an MBA. This is the limited repackaging of cognitive skills. Second, different skill axes are associated with distinct prices. This incomplete substitutability means that experience and school learning, or human skills and cognitive skills, are less than perfect substitutes.

2.1. Some important areas not covered in this paper.

A rich and useful literature has looked at the implications of wage dispersion for increasing income inequality. (See, e.g., Karoly, or Gottschalk and Smeeding (1997).) To reach those bottom line questions, one must obviously do much more than is done here, including (at least) attacking such interesting phenomena as race and gender wage differences, the covariance of wages with hours worked, multiple-earner households, the social safety net for non-earners, and so on.

Further, computerization is not the only force affecting labor demand. A complete story would take up the others. Other suggested hypotheses include increases in immigration, the de-unionization of the work force and other institutional changes, globalization of some industries, domestic changes in the conditions of competition in other industries, ongoing nonelectronic technical progress, and the emergence of “star systems” in many professions.[23]

Finally, I will not talk about labor supply at all, assuming that the papers discussed in this section have done their work well holding variations in supply fixed.[24] If that is the case, then the stylized facts reported here are those left over for demand to explain.

3. Computers’ Impact on Work: Technology and Timing

This section covers the history of computing and its uses from the perspective of the likely labor market impact. The goal is to get down in an organized way the largest technological events from a labor-demand perspective. To do that, I examine the history of the applications software running on computers rather than just computer hardware This makes the task difficult and the evidence thin.[25] I divide uses of computing into three main categories -- organizational computing, such as corporate accounting systems or transactions processing systems, scientific and technical computing in factories and laboratories, and individual productivity computing, such as word-processing or

[23] See Borjas, Freeman, and Katz, (1992) Borjas and Ramey, (1994) DiNardo, Fortin, and Lemieux, (1996) and Frank (1992).

[24] The supply-demand frameworks used in the papers are of independent methodological interest.

[25] Though the history of bits and bytes has been carefully investigated, the history of the use of computes is far less documented (Cortada (1996)).

computer-aided design.[26] The labor-demand impact of the three different kinds of use is distinct. The section concludes with the observation that it is the organizational computing which is most likely to have had substantial labor market implications and talks about its timing, size, and location within the economy and the labor market.

3.1. Diffusion by Value and Complexity: The Beginnings and Later Changes in Organization-wide computing.

Computers have become more powerful and less costly over time. Falling costs have permitted diffusion to less valuable applications. Rising power has let applications grow more complex. Organization-wide computing had the first, highest-value, applications.[27]

Computers began to be used extensively in business when computer power cost several orders of magnitude more than it does now, in the late 1950s and early 1960s. These systems were based on what was then called general purpose computers; i.e., mainframes. Accordingly, early commercial applications were in areas with large impact on using firms' costs, revenues, or service quality. Figure 2 shows the breakdown of applications in 1969, based on an IDC survey of about 2000 large computer users.[28] One strand of the diffusion of computers began in the sectors where the product itself is very nearly pure information, such as financial services. Another strand began in the information-intensive functional areas of many different kinds of companies, such as accounting, payroll, or inventory control. Looking at the listed applications, we see that their "user" is not a person but a department, typically a white collar bureaucracy.

Within organizational computing, diffusion of computing power moved forward on two margins. The number of mainframe computers grew rapidly from the mid 1950s to about 1973. Most large sites had a computer by then. After that, the count slowed, with a total of between 60 and 70 thousand in place through the 1970s and 1980s.[29] The total

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[26] This division largely follows industry practice (e.g., Inmon (1985)) and emphasizes the variety in the way computers are used. Most historians of the computer industry have emphasized the supply side. An important departure is Cortada (1996). Economists' writings on the industry have also focused on supply, market power, and technology. Bresnahan and Greenstein (1997) is an exception. Phister (1979) is a key source for quantitative materials on computers in use as well as computer technology.

[27] Economists somehow forgot this in the course of the "productivity paradox" debate. Yet there is little doubt that computerization in the 1950s and 1960s had very large social returns. See, e.g., Bresnahan (1986) for a quantification.

[28] The calculations based on the IDC(1969) were made by Phister (1979). See p. 455. I have aggregated some categories (for example, various banking and accounting ones) to make the diagram clearer.

[29] The definitional issues get much more difficult in the 1980s with the invention and spread of commercial minicomputers and even more difficult in the 1990s with competition from networked smaller computers against mainframes. For labor-market purposes, however, these definitional issues are not important and certainly do not change the timing story told in text.

amount of mainframe computer power continued to grow, as did the value of the installed base.[30]

Figure 2

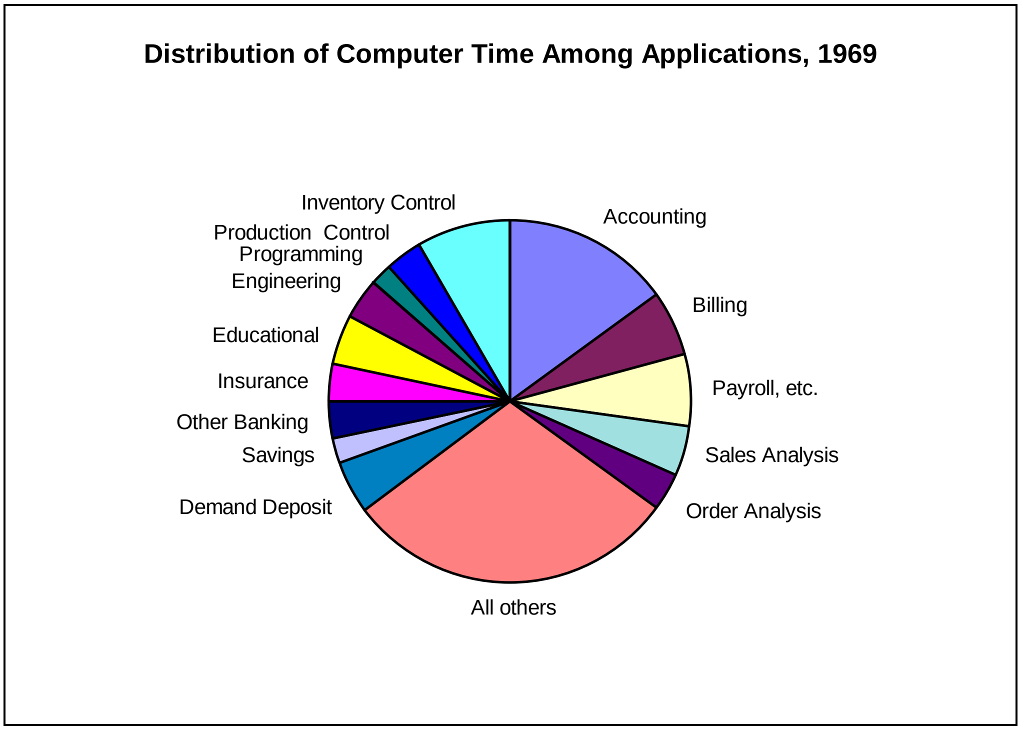


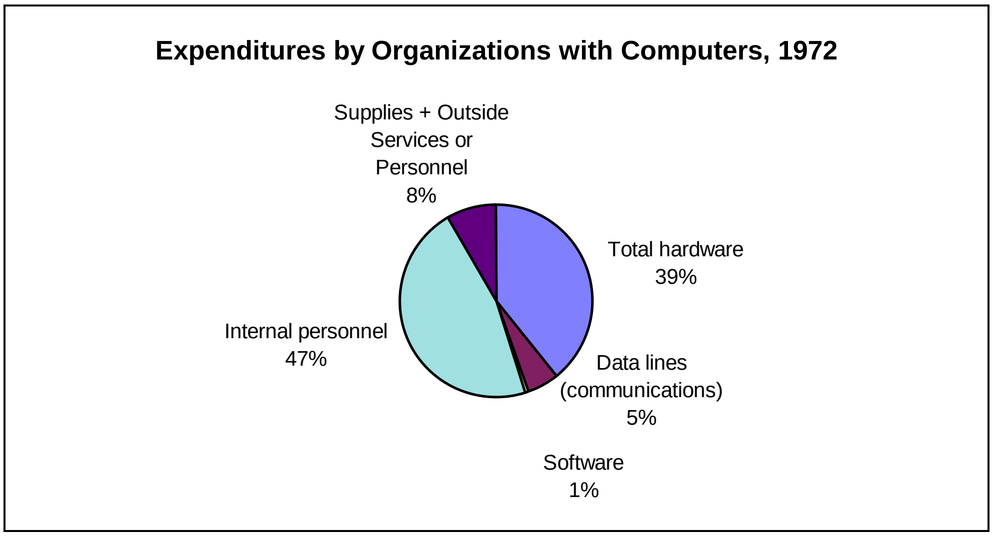
Figure 3 shows the expenditure breakdown for a typical MIS department in 1972.[31] Note that there is very little externally-obtained software at this time; basic software came bundled with computers, and applications software was largely written by consultants or by the MIS department itself. The most important implication is that, from a cost perspective, a very large fraction of inventive effort for business computer systems is done by the end-user organizations themselves rather than by computer hardware or software companies. Almost half of cost is internal people, largely computer programmers and the like.

Since the labor-demand impact of these systems affects all workers in the business process, it is worthwhile to ask simply how large that impact might have been. A simple calculation is how many people work in a building that has a mainframe computer in it in 1967 and again in 1971. For 1967, I use a report of the location of 28,034 mainframe computers by industry and by establishment size from IDC.[32] This shows the fraction of

[30] The data in the figures are based on the IDC EDP Industry Report. The valuation of the installed base here follows industry convention in valuing models still in the marketplace at current new-computer prices.
[31] See McLaughlin 1973. This is the first of the annual Datamation surveys of MIS department budgets.
[32] IDC reported a breakdown of computers in use by establishment size in an report called EDP/IR. I am thankful to Shane Greenstein for early copies of this publication. Phister (1979) reports a tabulation by industry by establishment size by industry for 1967.

establishments with a computer for employment size classes and approximately 1 digit industry in 1967. I then use breakdowns of employment by industry/establishment size class based on social security records[33] Assigning mean numbers of employees to each cell,[34] I can calculate the percentage of employees working in computerized establishments. In 1967, this is 21%. If I ignore the industry variation, I still get 21%. Accordingly, I calculate the same figures (without industry variation) for 1971, when the IDC report shows the location of 55,360 computers. At that time, 32% of the covered workforce worked in a computerized establishment. Clearly, this is not an accurate measure of the number of people whose jobs have been impacted by computers, but it suggests that an early labor market impact of substantial magnitude is possible.[35]

Figure 3



The number, kind, and complexity of organizational applications continued to grow -- within the same sites -- particularly as fundamental software and networking technologies such as database management systems and communications controllers spread in the 1970s and 1980s.

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[33] I exclude the agricultural and government sectors since my data source is social security. The larger employment size classes are aggregated so that the two data sources conform.

[34] From Statistical Abstract of the United States, 1969, Table No. 689. Reporting Units and Employment Under Social Security, by Employment Size, By Industry: 1967.

[35] The calculation overcounts workers whose functions have not yet been computerized, and undercounts workers affected by computing but located outside the establishment In the late 1960s and early 1970s, the overcount error almost certainly dominates. But the dramatic increase in the use of terminals connected to host computers in the 1970s means that there was a rapid growth in the undercounted portion. The fraction of the workforce whose work was computerized was rising more rapidly than the figures I report in text suggest, i.e., more rapidly than 50% in four years.

The same kinds of applications spread later to smaller sites. At first, the costs of mainframes meant this spread came by time-sharing, service bureaus (e.g., ADP for payroll) or remote computing at a corporate site. After 1978 by the use of commercial minicomputers at the smaller sites themselves began to be important, and some very small sites even began to run organizational applications on PCs. Networked computing, host-based and on proprietary (largely IBM) networking protocols in the 1970s and 1980s, then on open systems in the 1990s has permitted more and more extensions of the geographical span of organizational applications.

The timing of organizational applications thus begins in the 1950s, accelerates in the 1960s and 1970s, and continues to the present day.

3.1.1. The Operational Side of Bureaucracies

White collar work does things, even though we deprecate those things as bureaucracy and paper-pushing. Computerization of any particular process came in stages (Barras (1990)). The first was "mere automation," especially of clerical tasks. Computers are good at repetitive tasks, and bureaucracies, in the pre-computer era, were full of repetitive tasks that might be automated. This affected the demand for middle- and lower-paid white collar workers in two ways. First, clerks of all types (record clerks such as billing clerks, auditing clerks, etc., information clerks such as check-in, reservations, etc.), and related administrative support personnel have some of their tasks taken over by the computer. Where a human clerk would, before, have completely handled a file or a transaction, now that task is split between humans and computer. This is a direct substitution of capital for labor.

We can see this in a clear and simple, if perhaps not fully representative example. Figure 4 shows employment of telephone operators for 1960, 1970, and (almost) annually thereafter. Telephone usage is trending strongly upward in this period, driving the demand for operators upward. But automation -- telephone switches are computers -- reverses that trend. If you think of an operator's job fifty years ago and now, you get some of the flavor of computer-based automation. Then, the operator "did" the production of call routing in a physical sense. This called for physical manipulation and a modest amount of cognitive skill. The operator also was responsible for interacting with customers. Not all of the decisionmaking part of an operator's job was simple,[36] but most of it has proved simple enough for computers to do. Now, the operator serves primarily as the voice of the computer. Accordingly, the desirable skills are less cognitive ones,

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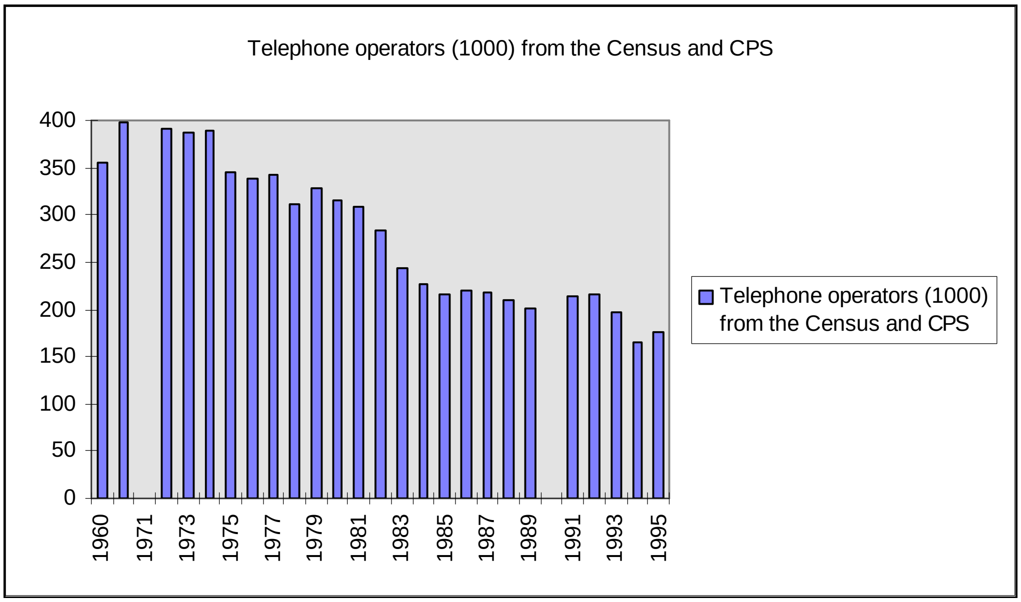
[36] "Technological innovations have changed the responsibilities of central office operators. Electronic switching systems have eliminated the need for manual switching, and new systems automatically record information about the length and cost of calls into a computer that processes the billing statements. It is also now possible in most places to call other countries, person-to-person, or collect without the help of an operator. The task of responding to "intercept" calls (vacant, changed, or disconnected numbers) also is automated, and a computerized recording explains the reason for the interception and gives the new number. The monitoring and computing of charges on calls from pay telephones also have an automated function formerly performed by operators." From the online Occupatoinal Outlook Handbook, http://stats.bls.gov/oco/ocos154.htm.

more conversational ones.[37] The automation has also introduced an extremely effective monitoring technology, so this job is no longer suitable for those who like to chat on the phone.[38] Finally, broader economic changes have relocated the bulk of operators: only about 3 out of 4 works in a telephone company, the rest "operate" PBXs in large organizations, often those with transient telephone call-receiving populations like hotels and hospitals. The human worker has been turned into a part of a computer system, only doing those tasks which are not economic for the computer to do.

Figure 4



Much of this change is representative of what computers do to labor demand in the operational side of white collar work. Decisionmaking tasks shift from the worker to the system. So do control, and in a routinized and systematized environment, monitoring. Workers need more people skills, and less cognitive ones. Jobs are redefined in a way that changes workers' tasks and thus skill requirements.

There are two very clear senses in which telephone switching is unrepresentative of other white collar business processes. First, it is nicely isolated from the rest of the organization and thus provides an unrepresentatively "clean" example. (That is why I

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[37] "Telephone operators should be pleasant, courteous, and patient. A clear, pleasing voice and good hearing are important. In addition to being a good listener, prospective operators should have good reading, spelling, and arithmetic skills. Good eye-hand coordination and manual dexterity are useful, as is an ability to work well under pressure." ibid.

[38] "The job of a telephone operator requires little physical exertion; during peak calling periods, however, the pace at the switchboard may be hectic. Telephone companies continually strive to increase operator efficiency, and this can create a tense work environment. An operator's work generally is quite repetitive and, in telephone companies, is closely supervised. Computerized pacing and monitoring by supervisors, combined with the rapid pace, may cause stress. Operators must sit for long periods and usually need supervisory approval to leave their work stations." ibid.

picked it.) This will turn out to be quite important, as the effect of computers on operators' jobs foreshadows one but not all of the substitution impacts we see in more complicated bureaucracies. Second, and critically important, there is not much that the combined operator-computer team can do to increase the demand for phone calls or to increase switching's share in the production costs of phone calls. This, too, is unrepresentative as much computer-based production in service industries permits large increases in product quality or even the introduction of whole new services, expanding quantity demanded.

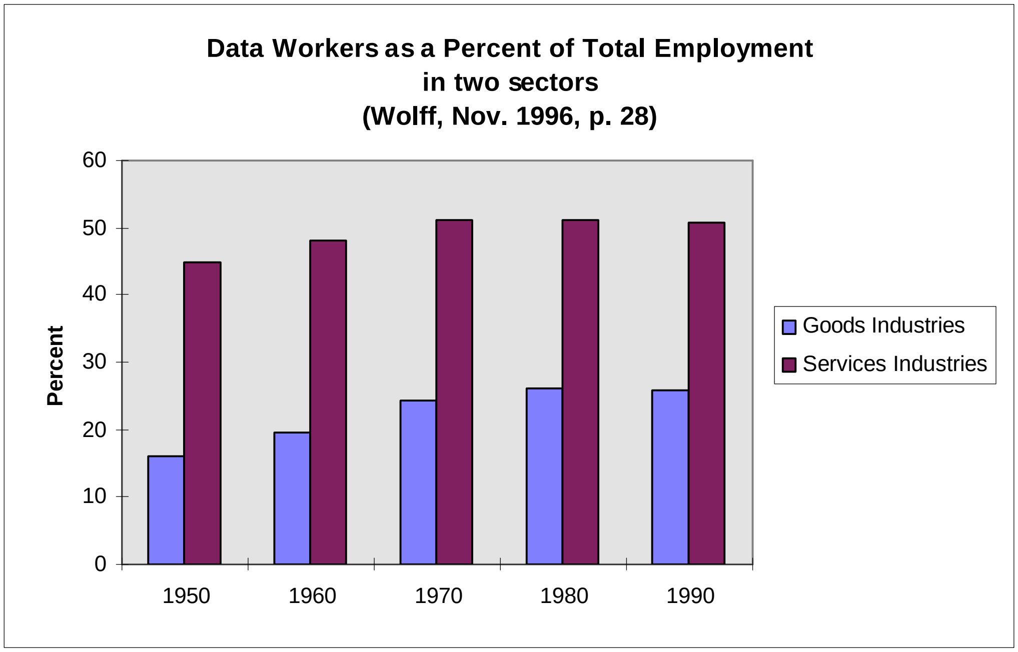
3.1.2. The Back Office and Data Workers

The first thing to note about potentially computerizable work that is more deeply embedded in complex bureaucratic processes is that more changes. In particular, shifting tasks to the computer involves complex shifts in the definitions of several jobs and in their skill requirements. One important form of this changed skill requirement was the creation of new specialties for white collar work via its separation into "front office" and "back office" components. The back office is an industrialized data-handling shop whose job was to turn business information into data for computer processing. The job of data-entry clerk was created and employment in this category grew rapidly. Typically this involves less skill than an administrative support clerical job. The data entry clerk is responsible for accurate transmission of data into machine readable form, but is more efficient when <u>not</u> thinking about the content of the information.

More generally, new specialties began to arise or grow in the area Wolff (1996b) calls "data workers". These contrast with "knowledge workers," "goods workers," "service workers," etc., in that data workers are users or handlers of knowledge, not producers of it.[39] Data workers include but are not limited to clerical workers, and Wolff rightly acknowledges the difficulty in defining the boundary between knowledge workers and data workers. Figure 5 shows data workers as fractions of total employment in the US goods and services sectors. Of course, the far more data-intensive service industries use more of this type of worker, by now about half of employment. As you can see, both series rise in the early period of organizational computing. Both decline in the 1980s, slightly. The technological history offers explanations of both the growth and its slowdown.

[39] Cf. p. 4 for more on the sources and definitions.

Figure 5



Computerization does not necessarily lower the demand for data workers, if the demand curve for business data processing is elastic enough. The lowered cost that comes from computerization expands data processing quantity demanded, raising demand for data workers.[40] As it turns out, an important technological fact has made the long run demand for business data processing elastic. Returning to Barras' (1990) multistage model of the invention of computer uses, the later stages are not mere automation of existing processes. Instead, they involve improving service and then adding whole new services. Where stage one might have been automated check-processing in a bank, the existence of a machine-readable checks database would lead to stage two, a sorted checking account statement. Barras argues that this is systematic throughout the service sectors of the economy.[41] Invention of new ways to use the capabilities offered by business data processing has been constant and ongoing. This complementary invention makes the long-run demand for business data processing elastic and accounts for much of the upward trend in data workers.

The more recent deceleration follows from another important technological fact. As computer technology, and especially the technology of using computers in organizations have matured, users have found more and more way to save data entry costs. This took both a narrow, technical form, as keypunch machines yielded to data-

[40] The relevant condition must relate the long run demand elasticity to the fall in labor's share in the cost of business data processing. While there has been little work on measuring the demand elasticity, the growth in the services sector and in services function employment suggests that it is far from zero. There are, of course, exceptions such as the telephone example cited above. These appear to be instances in which the service quality enhancement mechanism does not strongly influence demand.

[41] The same indirect invention process appears to have characterized the more information-intensive functions of other industries, such as accounting functions.

entry screens with certain error correction. More importantly, it was driven by a broader organizational and interorganizational use of data. (1) The costliest part of a database is data entry. As more and more business records were computerized, there began to be duplicative data entry. Fundamental technical advances such as the relational DBMS (and the corresponding changes in record keeping practices) permit economizing on data entry by removing this duplication. Technologies such as OCR began to capture documents rather than retype them. (2) As white collar work or even customer interactions -- think of the automatic teller machine -- became more and more computer based, data began to cross the boundary into the machine-readable state automatically. The existence of easy-to-use PC and terminals meant that data entry could become a small part of larger jobs. Back office shops began to disappear, and terminals or PCs appeared in the departments that needed the data. (3) As more and more transactions between different organizations were automated, the need for buyer and seller to separately enter data declined. Such technologies as electronic data interchange (EDI) and electronic fund transfer (EFT) allowed data worker cost savings. Thus, while the demand for business data processing has grown dramatically, its industrialization has permitted substantial labor-saving technical progress.

This trend will continue into the future. Ongoing improvements in computer ease-of-use mean that more and more workers and customers can do data entry or data queries as part of their normal duties. This will permit more and more replacement of production processes in which one person reads another a number over the phone while the second types at a computer, or one writes on a form for another to key in. Data entry workers, and data workers generally, are industrialized white collar workers. Once a production process has been routinized and regularized, it is subject to the same kind of labor-saving technical change as a factory floor. Every task is done as few times as possible, by the cost-minimizing person, so that the demand for low-skill white collar work trends downward.

Already this subsection has shown that there are several aspects of organizational computing related to the labor demand stylized facts. The subsection began with the goal of getting **F5 Timing** and **F6 Industry** right. There is, also, the attractive beginning of a story about **F1 Cognitive Skills and F2 Twist.** The substitution described here is clearly limited in its scope.

3.1.3. The Front Office and the Overall Impact On Clerical Work

The second half of the computerization of clerical work, the front office, had a different impact on the demand for white collar labor. Let me once again begin from the technical change side, turning now to the difficulties rather than the advantages of inventing business computer systems. Many writers have observed considerable learning by using in the invention of computer applications. Systems don't do quite what was hoped of them when first introduced, or sometimes what was hoped of them was based on a misunderstanding of the possibilities implied by the new technology.[42]

[42] Friedman (1989) offers the very interesting observation that once using organizations solved the basic technical problems of controlling hardware and software, they revealed the far more difficult problem of user requirements.

We can learn a good deal about front office human/computer substitution by thinking about the early stages of learning by using. Early applications lacked the commonsense of clerks, for example sending bills for $0.00. Only slowly did software systems improve. Over time, the foolish errors (remit $0.00) disappeared. From a technical-change perspective, we note that managers and management information systems people had to learn that computers lack common sense. A computer needs to be told not to send a bill for $0.00, whereas (many) clerks could be relied upon to do this without explicit instruction. Typically, the process by which these simple mistakes disappeared was trial-and-error. Managers were learning how literal-minded computers are relative to humans. Managers were also learning the rules that the clerks had been applying implicitly. These then became embedded in software. Even human common sense, where it could be represented by rules, came to be embedded in software. After some iteration on this learning-by-using-computers technological development process, business computer systems could perform basic accounting and transactions tasks in a far more careful and complete way than humans had, cheaper and faster. And computers' disadvantages, such as lack of commonsense, were overcome.

The impact on the labor market is that much of the routine decisionmaking formerly undertaken by clerical workers passed to the computer.[43] Much of the knowledge needed to make decisions came to be represented in databases and programs.[44] Since the 1970's, software tools have been advancing to permit more and more complex "business rules" to be embedded in computer systems. Accordingly, more and more complex transactional/operational tasks have been able to migrate from human to computer decisionmaking. This means that the multistep process of learning by using continues into the present day.

There are two very different understandings of what this has meant for front-office workers, and not much empirical research to tell them apart.[45] Either view means a large change in the demand for skills, though each view has a different set of implications.

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[43] I use the word "decisionmaking" advisedly. It is of no concern to us here whether computers have what a cognitive scientist would recognize as either intelligence or common sense. It simply means that they could make some decisions, once they were regularized and routinized, that had once been made by humans.

[44] Zuboff (1988) provides a very interesting analysis of this process. In one chapter, she examines computerization in an insurance company. The *ex ante* business system is people- and paper-based. In it, clerks took responsibility for both the physical handling of claims files and their logical handling. Determination of a claim's validity, for example, was typically done by the clerk having responsibility for the file. Exceptions were passed to managers, but the screen for that was also the clerk's responsibility. The rules used by the clerks were not terribly complex cognitively. Is the file complete? Is the policy paid up? Yet they do involve thinking as well as doing. Computerization in this environment took the form of writing a software program that could do this simple thinking.

[45] The main strands of research have been normative rather than positive and have used (interesting!) anecdotes rather that systematic investigation. One normative research literature seeks to advise business people on how to computerize organizations. Zuboff (1988) is a very interesting example. Sociology has contained two normative literatures,

One view emphasizes the shift of decisionmaking out of clerical workers' hands into software. The computer system came, first through a printed report and then through a screen display, to tell the front office worker what to do. The human worker does the things the computer cannot do well at all: speak to someone in person or on the telephone, turn vague customer inquiries into ones precise enough to answer, and so on. The labor market implications were to switch the skill basis of front office clerical work away from cognitive skills toward "people" skills. The human no longer makes decisions; or the decisions that the human makes are of the "what button to push" form -- the computer system lays out the universe of ways that a human "telephone server" can act. On the other hand, the human worker is now particularly valuable in a bridge role between a system and a customer or supplier.

The other view of the computerization of the routine part of clerical work is that it frees the human front office worker to make higher level decisions based on the information offered by the computer. A order-entry clerk may stop simply being an order-taker, and may instead suggest something else that the customer might like to buy. This increase in clerical people's sales roles calls for an increase in people skills, of course, and it likely also calls for an increase in autonomy. Other examples have more of a problem-solving flavor. The computer system may be, despite its years of development, too rigid to accomplish just what is needed in a particular transaction. The computer-using front office clerk may be empowered to type away at the terminal until the system can be tweaked into doing the commonsense thing. This interesting view calls for autonomy, people skills, and cognitive skills in the front office person.

It is clear from the anecdotal evidence that some of both kinds of change occurred in the middle of bureaucracies over the last three decades. It is not clear what the mix was.

In the aggregate, organizational computerization had a profound impact on the skill content of clerical work. Clerks need not think very much, though if they are talking on the phone to someone they need to be nice and precise at once. Decisionmaking has passed from human to computer. In the aggregate, the skill content of human jobs within business data processing -- which always went on, even before computers -- has lessened in the cognitive dimension and increased in the people skills dimension. The exact boundary of the limited substitution between computer decisionmaking and human decisionmaking is unclear.

This subsection has illuminated a somewhat different part of the ability of organizational computing to explain the labor market stylized facts. Since the changes in this part of low-level bureaucratic work were closely linked to those in the previous subsection, many of the same lessons apply. We further learn, however, that the exact boundary between substitution for human cognitive skills and complementarity with them that explains the **F2 Twist** stylized fact is hard to measure. Further, we learn that computers have had a large impact on the demand for certain people or interactive skills in the operations parts of bureaucracies, related to **F4 People Skill.** Finally, I note that the entire story about clerical labor has been one about changing the assignment of tasks. The

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one arguing that computerization is bad, the other that it is good, for office workers. See Hughes (1989) for a review of this literature.

reassignment changes the whole organization, calling for changed bundles of human capabilities. This seems to take us back to the basic point that repackaging is limited and that specific bundles of skills are the unit of demand, **F0: Basic.**

3.1.4. Management Needs More Cognitive and People Skills

The transformation of the operational side of white collar work into an industrialized, regularized and routinized process also had large impacts on managerial and professional work. This now takes us into the upper part of the income distribution. This kind of technical change has left a good deal more evidence behind in a normative literature for managers than in a positive one focused on labor.[46] Yet the labor market lessons seem to be implied by the advice to capital.

A computerized white collar process offers tremendous opportunities for incremental technical progress in a computer-using organization. Once a database of transactions and a crude set of rules for dealing with each one have been built, managers can process them better in any of a wide variety of ways. Marketing managers now have the opportunity to know much more about customers. Computerization has led to an explosion in a wide variety of sectors of thinking about how to market. There is a research and thinking component here, in which the systematic and routine nature of the computer database provides the underpinnings. Computers also change marketing operations, especially in service industries (including trade and commerce, the service end of the goods-producing industries.) Once research has discovered what customers want, the computerized production process can be changed to deliver it. This is typically not trivial, involving the definition of new services permitted by the expanded production opportunities.

There is a parallel on the accounting and control side of bureaucracies. The existence of large operational databases allows research into where the incentive problems are in an organization internally or in its relationships with customers and with suppliers. Research can predict who pays slowly, and, on the other side of a trade-credit relationship, whom one can safely pay slowly. Within the firm, research can show who is an effective sales person, an effective lower-level manager, etc. Once the characteristics of trading partners are understood analytically, the routinized and regularized computer-based system offers the opportunity to do something about it. New operations rules can evolve in order to offer better incentives or to monitor the right things. This is not typically trivial, either, involving the setup of new incentive contracts, new forms of monitoring and reporting, and so on.

Other functions' managers of course have faced the same dual opportunities. I focus on marketing and on accounting managers only to emphasize the wide range of managerial tasks that have been impacted by computers. The record of several decades of research and operational technical progress is very impressive,[47] but it has called for a new and apparently scarce skill set from managers.[48]

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[46] See Zuboff (1988). See also Applegate and Cash (1988).

[47] The amount of practical knowledge about markets and about incentives that has been embedded in software is stunning. Who would have thought, in 1960, that extension of convenient credit to a large number of consumers via credit cards was possible, since real-

The extension of computerized production to more and more complex kinds of transactions, and the linking together of more and more data, has meant that the process of (1) reacting to the research opportunities presented by data and (2) turning them into new operational realities has been a regular feature of managerial life in the computer age.

Obviously, the new research and thinking opportunities call for high levels of cognitive capability in managers. In service companies, the marketing function has become R&D-like, charged with understanding, in a quantitative way as well as the traditional ways, customer behavior. So, too, managers have had to use quantitative tools as well as their traditional people tools to think about incentives and monitoring. This is clearly related to the rising demand for large bundles of cognitive skills, **F2**. Somewhat surprisingly, the second half of the new managerial system has been even more challenging to managerial skills. It turns out that effective design of new service products, once the desirable ones have been identified, calls for not only quantitative skills but also traditional marketing and people skills. The design of new incentive schemes, for real people not the radically rational ones of our theories, calls for as much EQ as IQ.

Changes in company structure permitted by improved information flows have changed managerial skill requirements in another way. As bureaucracies grow flatter, and as the jobs in the bottom of the bureaucracies change, monitoring, supervision, and oversight change as well. Managers' skill requirements have moved correspondingly upward. This cluster of changes speaks directly to **F4 People Skill.**

Many large organizations are now a generation or even two of managers into this process of change. This reveals an interesting side effect of the joint transformation of low-level and high-level bureaucratic work. Many career paths involve first doing an operation and then supervising doing it. As the doing is done more and more by the computer, opportunities for human capital formation change. Deep knowledge of the production process may no longer come automatically from early experience. This is the closest I can come to directly explaining **F3 Experience;** of course, the rising price of experience may relate to other skills for which experience is a proxy, such as wisdom.

3.1.5. The MIS department and Computer Programming

Another driver of cognitive skills has been in the largely technical jobs in computer departments of large organizations. Management information systems departments, and later a broad class of technical support specialties related to decentralized computing, became an important form of job. Figure 6 shows the economywide implications of this development. The total number of computer programmers, systems analysts, and related

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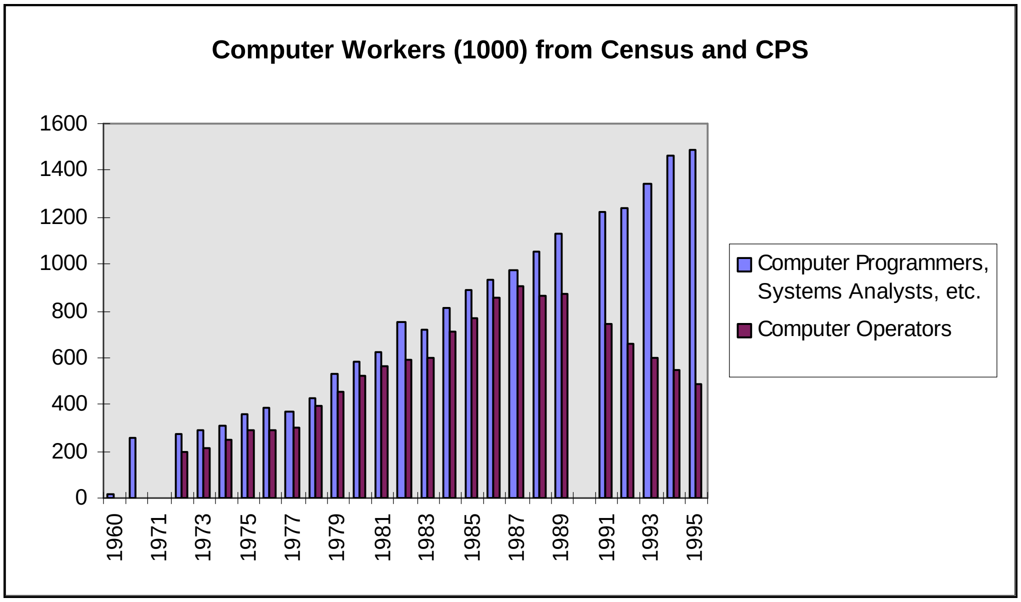
time monitoring of purchases would permit the creation of elaborate statistical models for predicting and detecting fraudulent use? The modern economy is filled with thousands of similar inventions.

[48] Interestingly, there has been an attempt, with much more limited success, to substitute computers for managers or other high-level operational personnel. This was the first view of "artificial intelligence." I conjecture that the limited substitution of AI for managers and professionals has to do with the growing noncognitive component of their work in organizations. Some of AI's successes -- in medical diagnosis support and in loan underwriting -- are in very high cognitive-content environments.

people rose steadily. One can hardly see the bar in 1960, after which the (almost) complete 1970-1995 time series shows ongoing growth. These workers are distributed throughout the economy, though a large concentration of them is in the computer services industry, which offers custom programming, consulting, and systems integration to user companies on an outsourced basis. These workers have high level of specifically technical cognitive skills.

Figure 6



Friedman (1989) writes of three eras in the history of MIS department. In the first two of these three eras, the cognitive challenge was to master hardware, then software. This was a purely technical challenge. In the third era, dated perhaps from the 1970s, it is the problem of "user relations" that is the cognitive challenge. This means that the MIS department no longer struggles to get the computer to do what it wants. Instead, it struggles to know what the organization wants the computer to do. This raises the skill demands on MIS personnel. Now they must have not only technical but also human interactive skills, ideally embodied in the same person. The ideal employees have project management as well as the technical skills. They also need "diplomatic" skills to deal with the business units. Such job title innovations as the "systems analyst" and the "chief information officer" reflect this trend.

The same figure shows the history of computer operators and related personnel, the blue-collar side of organizational computing. Demand for this kind of worker was growing for a long time. Two changes have led to a recent reversal in the growth. First, improvements in the quality, notably the reliability, of computer systems mean they need fewer tenders. MIS managers now talk of "lights out" (no humans in the computer center) and "7 by 24" (no scheduled maintenance) operations. The second trend is to distribution of organizational computing to departments. Such computer operator tasks as handling paper output are no longer specialized, instead being a small portion of computer users' jobs.

Examination of these technical specialties reinforces several of the themes that arose in the bureaucratic/organizational analysis earlier. The element of non-repackaging

(**F0**) is strongly present. Very specific bundles of cognitive and noncognitive skills are rising in demand. A large number of medium cognitive skill workers are not a good substitute for a few high cognitive skill workers, nor are high cognitive skills alone highly valued. So we see, again, strong (**F1, F2, F4**) elements even in this technical domain. Finally, we see once again the tendency for certain low-skill tasks to be first specialized and later distributed to other functions as technology changed. This reinforces the view that the demand for low cognitive-skill tasks, and thus for small bundles of cognitive skills, is heavily influenced by technology. This is another (**F2**) twist finding.

3.2. Technical Computing

Computers are a general purpose technology that can be adapted to a wide variety of uses. Moving now from commercial organizations to technical ones as the demanders, we see that they have made qualitatively different uses of computers. Factories, engineering departments, and scientists used minicomputers. (Some very large scientific applications used mainframes until the largest minicomputers came to be as big as mainframes.) Their applications were technical, numerical calculations rather than data processing. Minicomputers have been far cheaper than mainframes, and less numerous until 1973. The fraction of value of the installed base of computers represented by mainframes fell slowly, from 95% in the mid-1960s to 90% in the mid-1970s. Over the same span the fraction of computers that were mainframes fell to half.

Minicomputers entered the production process in a completely different way, as "controllers" or "instruments" in factories and laboratories. These applications did not tend to change the organization of a factory or lab in any direct way. They acted as extensions of the scientists' and engineers' toolkit. Of course, much of the engineers' task was to make the factory more efficient, so the use of computerized process control and process measurement indirectly contributed to the steady productivity gains of manufacturing. Overall, however, the right inference about minicomputers in the early stages of computerization probably is best drawn from their simple capabilities and low prices. They were unlikely to have a large impact on labor demand.

Figure 7 shows the distribution of industries where computers of any kind could be found as of the mid 1960s. The figure reflects contemporary data[49] and simply reports the number of computers present per dollar of value added and per employee. As you can see, there are a great many in manufacturing. This figure suggests a quite different distribution of all computers than the distribution of commercial/mainframe computers we saw above.

Minicomputer technology did have some impact on the demand for scientists and engineers, by making them more useful and valuable. As design and automation software improved over time, CAD/CAM applications in a wide variety of manufacturing industries became important. The individual-engineer's workstation was invented, and software evolved to increase the productivity of individual engineers. Even personal computers were used to support individual engineers in CAD applications.

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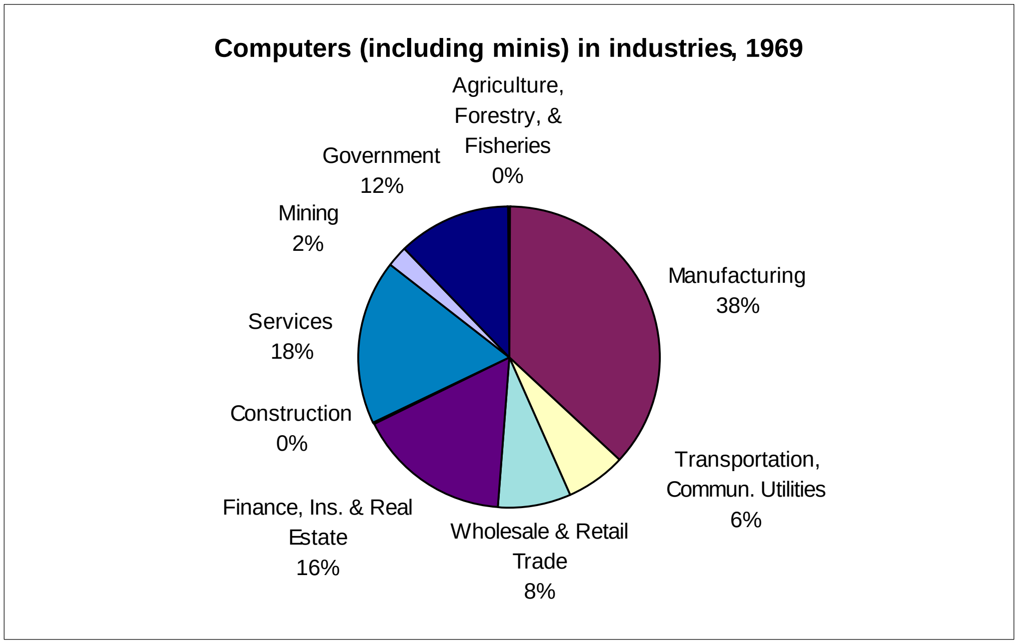
[49] It comes from an IDC EPD/IR report.

Figure 7



This part of technical work is, like the MIS departments above and the computer industry treated below, quite encouraging for the conventional theory of complementarity between cognitive skills and computers. The technical people whose productivity is raised have, first and foremost, cognitive skills. And they tend to be literally sitting at a computer when a computer influences their job.

3.3. The Computer, Software, and Networking Industries Themselves.

At least for the US, if not for other rich countries, the supplying industry made a nontrivial impact on labor demand. At its peak, IBM numbered a million employees. More generally, the demand for scientific and technical personnel implied by the existence of a large and inventive electronics sector. This relates most directly to the demand for cognitive skills, especially quantitative and technical ones.

3.4. The PC as an important Skill-Enhancing Technology (not) and the 1980s as the time of ICT's impact on the workplace (not)

A number of studies have looked for complementarities between knowledge workers' or symbolic analysts' skills and ICT by examining computer use at work.[50] A subset looks at the wages of the computer users themselves, interpreting higher wages as evidence of the complementarity. Most direct users of computers use a PC, with some using a terminal. The studies have focused more on the PC use. The argument is that computer users are doing analytical tasks, the kind of brainwork which is the future of work generally. The rapid diffusion of the PC into a wide variety of white-collar workplaces completes the argument; from 1984 to 1993, AKK report, the fraction of

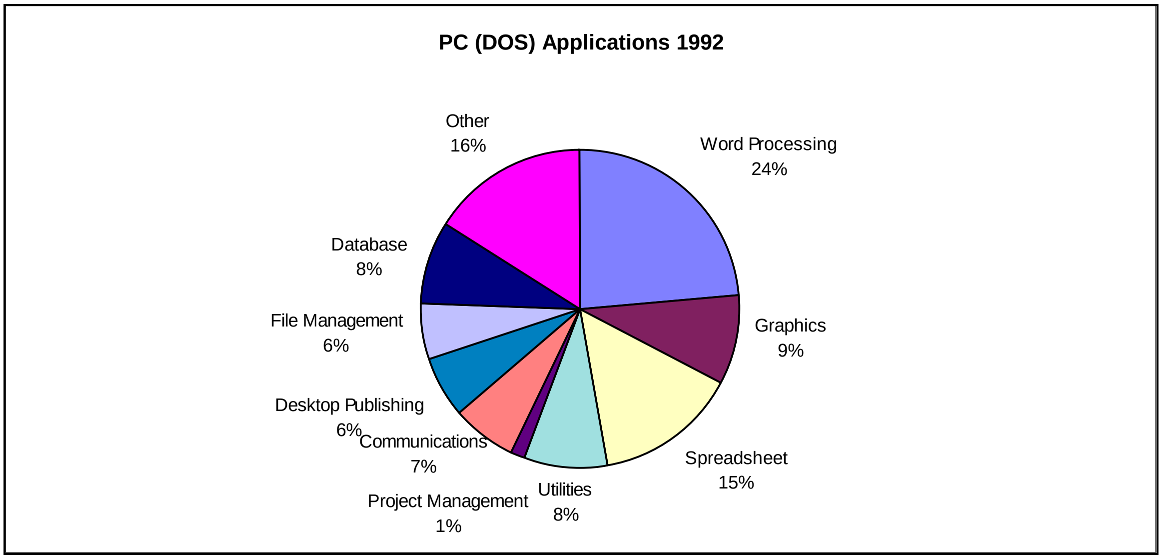
[50] Krueger, Autor Katz and Krueger, Mairesse. Dinardo and Pischke.

employed people using a computer rose from 25.1% to 46.6%.[51] This is surely a large enough trend to have aggregate labor market impact.

Critics have doubted the interpretation, arguing the reverse causality that PCs have flowed to the high-wage jobs. The result that pencil use at work predicts wages at least as well as computer use, reported by Dinardo and Pischke (1997) has emboldened the critics. Just as the original studies reported that they were testing for computer-skill complementarity, the revisionist interpretation is that there are no such complementarities. I agree wholeheartedly that there is little complementarity between highly skilled workers and PC use, certainly not enough to affect skill demand.

The economic interpretation of both the studies and the criticisms should be tempered by an examination of the facts of PC use at work. Figure 8 shows a survey of applications used at work.[52] First, by far the most important use of PCs is for word processing; it comes to about a quarter of PC use. While word processing raises the productivity of secretaries and typists, this seems a very implausible source of wage dispersion and a silly definition of "knowledge workers" or "symbolic analysts." Managers, professionals and technical workers who now do their own typing with easy-to-use PCs are likely somewhat more productive than before, but this is another very unpromising source of widening wage dispersion. The second largest PC application is spreadsheets; word processing and spreadsheets together accounted for some 90% of PC use at the end of the 1980s. Much the same problem arises as with word processing. The typical spreadsheet user is a midlevel clerk or accountant. As with word processing, individual productivity is enhanced, but not in a way that suggests an explanation of the changed return to cognitive skills at the high end..

Figure 8



[51] Cf. table 4. The underlying source is the CPS.

[52] This comes from Computer Intelligence Infocorp, and is based on a large sample of business computer users -- sampled at home. The figure shows DOS users. Windows users are quite similar, and Mac users vary primarily in using more graphics applications and fewer database applications.

A minority of PCs did run some software that is promising for the individual cognitive skills complementarity hypothesis. Some of the uses are associated with high-skill and high-productivity applications in the upper half of the income distribution. The major examples are computer-aided-design (CAD) and related programs for design engineers, architects, and the like, desk-top-publishing (DTP) for marketing and communications experts, databases for analysis of company databases, project management and presentation and graphics programs for salespeople. Several of these categories are clumped under "graphics" in Figure 8, so the total amount of such usage appears to be on the order of 20% of uses.[53]

The strong conclusion to draw is about measurement. Individual wage equations with a regressor for computer use are a very bad place to look for the main linkages between computerization and labor demand.[54] PC use includes too many low-status jobs to be much of an indicator for skill complementarity. It also misses all the highly skilled managers who don't literally use computers (perhaps getting a computer-based report from a subordinate) but whose skills are highly complemented by the computerization of the organization.

A weaker point is that PCs are not all that important a technology for labor demand. They mark the continuation of a long term trend to computerization of work. Their lower prices and smaller scale mean that they can be deployed in far greater numbers than earlier, larger computers. It also means that they can be deployed in uses which have far less of an effect on labor demand.

What is really important about the 1980s, a time of considerable expansion in total IT investment, is not so much the PC itself. Instead, this was a time in which technical progress on a very wide range of fronts opened up new opportunities for the use of computers. Those included two strong movements in the direction of smaller sites -- the PC, and the commercial minicomputer. But they also included strong movements in the direction of larger and more complex applications, as host-based networking protocols, relational databases, and communcations controllers diffused into large organizations.

3.5. The Organizational Focus

In the last few sections, I have focused much more a specific range of computer systems, those affecting white collar work in bureaucracies. I focus far less on minicomputers and workstations in factories and labs as well as PCs on desks Isn't this just ancient history, looking back at the earliest uses of computer technology and missing such large events as the PC revolution? I think not, for a cluster of related reasons.

First, however you look at it, organizational computing is a very large part of computing. Even a far too conservative measure, just looking at hardware systems

[53] Looking at the value of shipments in the PC applications software market yields a similar story. See, e.g., the report by the Software Publishers Association, reprinted on pp. 354--355 of the 1994-1995 Computer Industry Almanac.

[54] Some studies use the fraction of workers using computers in a firm or industry as an indicator of ICT intensity. This is more defensible, thought it is obvious from my remarks in the section above that it is business systems rather than individual computer use which are a good indicator of an ICT-intensive organization.

acquisitions, reveals this. If we simply examine purchases of computer systems by dollar value in the period of changing wages, organizational computing starts at almost 100% and falls, by the late 1980s, to just under half.[55] A somewhat more sensible accounting exercise, if a harder one, would be to look at the total value of computer systems -- including not only externally acquired hardware, software and networking, but also user-created software and business systems and the rest of costly coinvention. This would make organizational computing loom far larger even in the late 1980s. It is hard to speak quantitatively to this, although it is clearly right to depreciate the software component of organizational business systems very slowly. Finally, a variety of studies of the behavior of computer users and of the structure of computer markets reveal that organizational computing involves a great deal more “off-budget” coinvention. This is because the costs of coinvention are far higher for commercial business systems performing mission-critical applications.[56] Market structure studies show that commercial computing segments involve much more support for the coinvention process, in the form of field sales forces, armies of consultants, and so on, than do personal or technical computing. This, too, arises because the organizational computing use involves changing far more than computers, it involves the wholesale redefining of jobs and retraining of workers.

Technical progress in ICT has not been a simple march toward cheaper versions of the same capital good. Instead, qualitative change in ICT has opened up new prospects for computer-using organizations. As a result, there have been, for fifty years now, repeated shocks to labor demand. Each new level of computer power, and each qualitatively new software or network functionality, permits the invention of new applications. As a result, new opportunities for shifting tasks between human and computer, and between people of different levels of skill within the organization, are found over and over. The impact on labor markets has not stopped. The newest results from Brynjolfsson and Hitt (1997), for example, show strong relationships of complementarity between ICT and certain changes in workplace organization even in the present.

The organizational focus does take us toward analysis of the firm, not the job, as the unit of labor demand. This has good and bad aspects. The conceptual advance in looking at the actual demanding unit is likely to be very helpful.[57] Individual worker

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[55] Making this calculation involves the difficult judgment call of which minicomputers are in commercial as opposed to technical use.

[56] See Bresnahan & Greenstein (1996) for evidence on this from users’ behavior in switching from mainframe-based to network-based computing systems. See Ito (1996) for evidence based on increases and decreases in the stock of computing at users sites. Both studies find very large sunk costs of computer systems above and beyond the hardware and software, and show that these are the costs of inventing new computer systems, changing workers’ jobs in a complementary way, and so on.

[57] Labor economists will no doubt have noted many amateurish moments in this draft paper, and I look forward to learning where they all are. I am struck, reading the labor economics literature, by how much more primitive the conceptualization of labor demand is than that of labor supply. Perhaps the field has had its collective thinking influenced by data availability.

datasets have been very powerful tools for investigating labor supply. It is not immediately clear what should replace them in the analysis of labor demand.[58]

The organizational focus also takes us toward analysis of several different aspects of work, not just supply and demand of worker commodities. The degree to which work is externally controlled or monitored, the nature of reporting and incentives, and related nonpecuniary aspects of work have been as important here as the demand for workers of given type. There is an underlying theme of information technology meets the information-economic approach to organizations in much of this, if not one I have explored very carefully in this paper.

The other reason to be particularly focused on organizational computing is that it is the wave of the future not of the past. Networking together PCs means that there is a technical opportunity to bring PC users into large, organizational systems. I will turn to this topic in some more detail in the last section.

3.6. What you have gotten here.

I look at the shape of the impact of computers on the labor market in detail and at its likely size in less detail. These sections really can't be thought of as providing hard evidence that the organizational computing hypothesis involves a large enough impact on workplaces to form an important part of the wage dispersion story. Rather, the argument has been the qualitative one that the main stylized facts about timing, locus, and multiple skills, are congruent with the theory. Part of the reason for this holding back is the incompleteness of the theory. There is much other technical progress in the economy, not particularly related to ICT and directly affecting skill demand. The other forces, globalization, changes in labor market institutions, etc., have some impact. But the bulk of the reason for not pushing forward to a more quantitative treatment is simpler; that will

[58] See Hamermesh (1993) for the menu of choices. Labor supply is one of social science's triumphs. Labor demand is harder.

be a lot of work and I haven't done it yet.[59] So what you get here is not very formal theory.[60]

4. Conclusion.

4.1. Reprise.

Information and communications technologies have been a powerful transforming force in white-collar work. Invention of ways to use computers in bureaucracies has meant the regularization and routinization of work, a process that has renewed itself steadily over 50 years. This has permitted increases in product and service quality in the parts of the economy, like services, where white collar work is a large part of production. It has also permitted changes in the functioning of the white collar portions of organizations more generally. The most important loci of this change have been company-wide or department-wide computer business systems, not individual workers' use of PCs. The important technologies from the perspective of the labor market are large computers, database management systems, transaction processors and the like.

The theory predicts the main stylized facts. The resulting technical change has been skill-biased. (a) Computer decisionmaking has systematically substituted for human decisionmaking in modest cognitive skill tasks. (b) Computers in organizations have been complementary to large bundles of cognitive skills, especially where these are bundled with people skills and experience. Taken together, these technological facts explain the rising price of cognitive skill and the "twist." The exact boundary between the substitution and the complementarity is quite difficult to pin down, so this explanation is a qualitative not a quantitative one. (c) Related to the complementarity with large bundles of mixed skills, and possibly exacerbated by changing career paths, computers have been

[59] The first fundamental challenge is the lack of good data on the purposes of computer systems at the individual organization level. It seems promising to push forward on two fronts for observables that are close to this. One front is just looking to see which organizations have used their ICT in a way that might have changed their labor demand. MIS budgets, MIS headcount, etc., seem to be more promising observables than applications software, not because they are conceptually simpler but because they are observable. A second front is characterizing computer using organizations by the complexity of their hardware and systems software. Shane Greenstein and I (in our Brookings Micro Paper) have built such a classification scheme which appears to have some success in predicting organzation-level demand.

The second fundamental challenge is deciding on the right frame to observe labor demand. ICT does not just change labor demand, it changes the organization of the firm -- including the boundaries of the firm and industry. Such phenomena as outsourcing, the increasing vertical disintegration of production, and so on, pose a difficult challenge for the measurement framework.

[60] There is a large and growing body of formal theory that may prove very helpful in this effort. I think of the new theory of organization, monitoring, and incentives in Milgrom and Roberts (1992) and of the attempt to link it tightly to labor economics in Gibbons (1996).

more substitutable for inexperienced than experienced white collar workers, raising the premium for experience. (d) Computer business systems have been complementary to "people skills," and to autonomy, raising their return.

The resulting shift in labor demand by skill -- or by skills -- has been dramatic. The changes have come at the time, and in the industries, primarily services, and the functions, primarily white collar, where organizational computing has had its largest impacts.

There has been a long-term trend in technical progress reducing the labor content of industrial processes, and a resulting long-term trend away from relatively low-wage blue-collar work toward higher paid occupations. What we need to explain the new inequality is something that accelerates that trend and extends it into white-collar work The organizational focus of this theory seems right for that. The most important aspect of computer-based technical change may lie in the particular nature of SBΔT in the growth sectors of the economy. We are living in an era of transformation. Older industries, like the goods-producing ones are declining as a source of employment and of worker rents, notably for lower-skilled people This is the typical behavior of old sectors in a transformation. The novelty is that the new growth sectors, mostly in services, are also substituting out of low-skill work. Rather than a process of shifting workers from older to growing sectors, we see a general crash in the demand for certain skill bundles.

4.2. The Future:

There is reason to believe that these labor demand trends will continue, and even accelerate. To make such a forecast, it is far from sufficient to point to Moore's law or to the rise of the internet. We must attack the much more difficult task of forecasting technical progress in the use of computing.[61] Since the returns to specific technical forecasts in this domain exceed the returns to specific forecasts of stock price movements, you should be cautious reading the rest of this subsection. There do seem to be some broad general trends at work, however, and these have implications for labor market futures in general.[62]

Fundamental technology drivers in information and communications technology have made networked computer business systems cheaper, higher performance, and easier to use. The first implication of this has been a burst of organizational computing invention. The new organizational computing takes advantage of technical progress in PCs as well as in networks.[63] With a PC on nearly every white collar desk, either "client/server" architectures or "intranets" can be used to make new, organization-wide

[61] Another perspective would be to look at the fundamental characteristics of computers and people and forecast on that basis. An interesting attempt in this direction is in Elliot (1997).

[62] Another view relegates economists to the role of historians: "It is, in my view, probably too early to determine just how much of the post-1980 technological change is due to computers . . . .But we will know more about the answer to this question in 20 years." Johnson (1997) p. 49.

[63] It is telling that the most important standards battle of the moment, that between the PC and the "net PC", is a battle over how not whether control of personal computing will be removed from individual workers and returned to their employers.

applications. The idea of these is that they should be as easy to use as PC applications but as powerful and useful as traditional organizational computing applications. From a labor market perspective, this will lead to a broadening and deepening of the trends associated with organizational computing generally. Tasks calling for modest bundles of cognitive skills will be increasingly automated. More complex tasks, calling for either larger bundles of cognitive skills or for people/cognitive skills bundles, will be demanded of workers.

How large will this be and how like or unlike the last 25 years? It is extremely difficult to forecast the point in the income distribution where substitution stops and complementarity begins. Will this point move? The big change from previous organizational computing is the universality of easy-to-use PCs and browsers. It is absolutely clear that this will permit new task divisions between humans and computers. To forecast, we need also know what knew operational efficiencies and customer services these technologies permit. This is deeply unknowable. I go with a persistence forecast for the intermediate run, knowing that technologists don't know these future directions either.[64] How large? There is no doubt that the early stages of the new networked organizational computing are at a very early stage of a very long diffusion process.[65] There will be very considerable impact.

A second point about networked computing is that it is permitting the extension of business computer systems to wider and wider geographical scope, and to cross company boundaries. For some time, business-to-business computer networking applications were confined to high information content and high value markets. A corporate treasurer, for example, might have in-office access to bank account information as good as that of the bank's employees themselves. Technical progress in the form of faster and cheaper connectivity permits, and invention in the using industries is now accomplishing, the extension of these kinds of connections to the rest of the economy. The distribution system between manufacturing and end customers is full of examples. Such business-to-business networking applications as supply chain management, automatic inventory replenishment, and intelligent logistics are examples of a cluster of new and wider extensions of the scope of computer decisionmaking.[66] There is vast scope here for the automation of white collar work. There still is a considerable amount of low skill white collar work in distribution, defined broadly to include wholesale and retail trade, goods transportation, and the buying and selling operations inside companies in general.

Less far along, but potentially very powerful, are business-to-consumer transaction applications using electronic commerce for improved service, mass customization, and

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[64] Information technology is permitting, or is rumored to permit, large changes in company structure, hierarchy, and incentives. Systematic research on this is at a very early stage even with regard to the recent past (see Brynjolfsson and Hitt for a very interesting example) much less to support a forecast.

[65] See my papers on this diffusion process with Shane Greenstein and Garth Saloner.

[66] Interestingly, the innovation in this area is largely driven by new ideas about ways to organize trade and commerce, with information technologies being used to implement. By far the most important invention in this area was the Walmart store. The labor demand shifts "caused" by computing are truly caused by the reorganization of firms and markets which computing permits, supports, or makes cheaper.

individualized advertising. Here the key technical change has been ease of use of microcomputers. These are just beginning to permit increased use of network for retail trade. Important parts of retail trade which are very information-intensive, such as retail banking and retail brokerage, are one nexus of change. Other areas where the customer is very informed about desirable product characteristics before beginning a purchase, such as music, software, books, and travel, form another nexus. Here there is considerable opportunity to substitute customer work for customer-plus-clerk work, a change reminiscent of the invention of self-service shopping. Now the computer, not the clerk, makes the sale.

The aggregate labor market implications of the extension of the computer into markets from its home base in organizations is very large. It is also hard to predict if the impact on labor markets will follow the past pattern. The finding of Brynjolfsson and Hitt (1996) that recent successful computer applications are shifting towards new models of incentives and reward is an example of the many reasons to be cautious. The amount of mid-skill white collar work that is spent simply doing transactions is stunning, however, so that there is scope for considerable invention of new computer-based market systems. It seems plausible that recent trends in labor market skill demand will continue.

On the side of complementarity with large bundles of cognitive skills, there is much the same story. If I have been right in the last few paragraphs about the likely areas for technical change using computers, even if I have been wrong about their low- and moderate-skill impact, there will be continuing pressure on the available stock of highly skilled people. Inventing those commercial applications and the organizations that can participate in them will call for extraordinary management skill and extraordinary technical skill in implementation. The organization-wide theory of the complementarity between highly-rewarded people and computers offers the most robust forecast. As long as there are new applications of computers either (a) in new areas of activity or (b) changing existing areas of activity in unpredictable ways, there will be pressure on technical and managerial cognitive and people skills.

4.3. Labor Supply Institutions.

While all this change in labor demand has been going on, labor supply institutions have been performing less effectively than they might have been.

The reigning explanation of labor market change focuses narrowly and single-mindedly on cognitive skills. The policy implications of this theory fall heavily on the school system. If the spread out of the income distribution is driven by a computer-induced rise in the return to cognitive skills, the appropriate supply response is an increase in total cognitive skills. The school system is the obvious place for this, and a policy debate about schooling has been opened at all levels.

In this paper, I have suggested two errors in this focus on schools as the only labor supply institution and on cognitive skills as the only ones in short supply. The two errors lead us to cling to a false hope about the school system and to miss some real opportunities.

The first error is that a broad-based schooling program in primary and secondary education addresses the changed demand for labor. If the theory advanced in this paper is correct, schooling and general cognitive skills are weak tools to increasing incomes in the bottom half of the wage distribution. The twist in the premium paid to cognitive skills means that investments in modest amounts of schooling earn about the same return as they always did. Families in the bottom half of the income distribution haven't failed to respond to market signals by failing to get more education for their children. The market signals just isn't there. The increased labor demand for cognitive skills fails "repackaging." No number of newly trained high school graduates can do the work of a lawyer or MBA in the new economy. A societal effort to train many more young people up to middle cognitive skills levels, say to finishing high school with medium standards, may well be pushing on a rope.[67]

One important exception is technical skills. The computer revolution has led to a shortage of people with technical training, and the school system may well help here. It seems unlikely that adding internet access to schools, or more generally, in computerizing schools, has much to do with solving this. The skills gaps will be for people who can design and repair the software of tomorrow, not use the software of today.

The second error is narrowly focusing on school learning and cognitive skills This misses the broad based increase in demand for noncognitive skills associated with ICT investment. Interpersonal skills, knowledge of the world of work, ability to work steadily and autonomously, flexibility, and reliability are all in increased The economic opportunity for people in the bottom half of the wage distribution may well lie in these noncognitive skill areas, and cognitive skills acquired and altered throughout work lives may be more valuable than those acquired in youth Certainly, one thing the new production processes reward is bundles of cognitive and noncognitive skills in the same person. Traditional schooling is a poor vehicle for providing these new skill sets, and changing the school system to provide them may not be the best route

Perhaps we are thinking about the schools too much when we look for opportunities to improve labor-supply institutions. Family, church, neighborhood, and club have all declined from the labor-supply roles they once played When these institutions played a stronger and more central role in more people's lives, they played a useful role in noncognitive human capital formation. People could learn many valuable even highly rewarded skills in these social interactions Their decline leaves a gap The debate over that gap has been more emotive than analytical, a mistake.

The bottom line policy message here is very positive. If we look at cognitive skills alone, the wage distribution story would be grim. Under the limited substitution theory, computerization of the workplace would lead to polarization. Low cognitive skill white collar work is industrialized, and substitution out of low cognitive skill white collar workers in the growth sectors of the economy becomes as rapid as substitution out of mechanically skilled workers in the older sectors The supply of cognitive skills comes from the native distribution of intelligence, parental attention, and the schools There is only so much the latter two forces can do with the native distribution If only cognitive skills mattered, the income distribution would be caught in an iron vise between limited possibilities of substitution between high- and low-skilled workers on the demand side

[67] Of course, primary and secondary schools lead toward highly rewarded higher education. My point, however, is that the income-distribution challenge we face has to do with economic opportunity for people who are unlikely to go on to higher education.

(failure of repackaging) and limited opportunities for supply substitution. But cognitive skills are very far from the whole story And the opportunity to move to new noncognitive skill sets, or mixed cognitive/noncognitive skill sets.

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