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COMPUTING INEQUALITY: HAVE COMPUTERS CHANGED THE LABOR MARKET?

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ABSTRACT

This paper examines the effect of technological change and other factors on the relative demand for workers with different education levels and on the recent growth of U.S. educational wage differentials. A simple supply-demand framework is used to interpret changes in the relative quantities, wages, and wage bill shares of workers by education in the aggregate U.S. labor market in each decade since 1940 and over the 1990 to 1995 period. The results suggest that the relative demand for college graduates grew more rapidly on average during the past twenty-five years (1970-95) than during the previous three decades (1940-70). The increased rate of growth of relative demand for college graduates beginning in the 1970s did not lead to an increase in the college/high school wage differential until the 1980s because the growth in the supply of college graduates increased even more sharply in the 1970s before returning to historical levels in the 1980s. The acceleration in demand shifts for more-skilled workers in the 1970s and 1980s relative to the 1960s is entirely accounted for by an increase in within-industry changes in skill utilization rather than between-industry employment shifts. Industries with large increases in the rate of skill upgrading in the 1970s and 1980s versus the 1960s are those with greater growth in employee computer usage, more computer capital per worker, and larger shares of computer investment as a share of total investment. The results suggest that the spread of computer technology may "explain" as much as 30 to 50 percent of the increase in the rate of growth of the relative demand for more-skilled workers since 1970.

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I. INTRODUCTION

Overall wage inequality and educational wage differentials have expanded substantially in the United States since the late 1970s. Much research suggests that a possible driving force behind these changes has been a large increase in the gap between the rate of growth of the relative demand for more-skilled workers and the rate of growth of the supply of such workers. Katz and Murphy (1992) emphasize both the deceleration in the rate of growth of the relative supply of college workers since the early 1980s and a possible acceleration in the rate of growth of the relative demand for the more-educated. An increase in the pace of skill-biased technological change (e.g., Bound and Johnson, 1992) and increased globalization pressures (e.g., Borjas and Ramey, 1995; Wood, 1994) have been offered as explanations for an acceleration in the growth of the relative demand for more-skilled workers in the 1980s. An alternative (or complementary) story for rising inequality has emphasized the decline in unions, the real value of the minimum wage, and pay-setting norms that have historically served to compress the wage structure (e.g., DiNardo, Fortin, and Lemieux, 1996; Freeman, 1996).

The skill-biased technological change explanation for rising wage inequality has much appeal to many labor market analysts. The rapid spread of microcomputers and computer-based technologies over the past 15 years provides a visible possible culprit. And Krueger (1993) has documented a substantial and growing wage differential associated with computer use from 1984 to 1989. The continued increase in the relative utilization of nonproduction workers and more-educated workers (particularly college graduates) within detailed industries and within establishments in the United States despite the rising relative price of these groups during the 1980s and 1990s suggests strong within-industry and within-establishment demand shifts favoring the more-educated (Davis and Haltiwanger, 1991; Berman, Bound, and Griliches, 1994).

Similar within-industry increases in the proportion of "skilled" workers are apparent during the 1980s in other OECD nations and the increases in skill demand are most rapid in the same set of manufacturing industries across OECD economies (Berman, Machin, and Bound, 1996). Skill-biased technological change is the "natural" name for economists to attach to unexplained within-sector and within-firm growth in the demand for skill.

Much recent evidence exists beyond such indirect inferences indicating that the relative utilization of more-skilled workers is positively correlated with capital intensity and the implementation of new technologies both across industries and across plants within a detailed industry.[1] These patterns strongly suggest that physical capital and new technologies currently appear to be relative complements with more-skilled workers.

But there are reasons to question whether an *acceleration* in the pace of skill-biased technological change is the primary reason for recent sharp increases in U.S. wage inequality and educational wage differentials. Technological change and capital-deepening appear to have been associated with increased demands for more skilled-workers for many decades including periods of stable and narrowing educational wage differentials. Furthermore Mishel and Bernstein (1996) find in a cross-industry analysis that the impact of some observable technology proxies on skill-upgrading appears no greater in the 1980s to early 1990s than it was from 1973 to 1979, a period of narrowing educational wage differentials. Goldin and Katz (1996a,b) show

[1] For example, Bartel and Lichtenberg (1987) find, from a panel of manufacturing industries from 1960 to 1980, that the implementation of new technologies is associated with an increase in the share of highly-educated labor in total labor cost. Doms, Dunne, and Troske (1997) show that U.S. manufacturing plants using more advanced technologies employ more-educated workers; but, they find that workers at these plants were relatively highly-educated even before these new technologies were implemented. Berman, Bound, and Griliches (1994) and Berndt, Morrison, and Rosenblum (1992) conclude that skill-upgrading in U.S. manufacturing is positively correlated with the growth of capital-intensity and the utilization of high-technology capital and investment in computers. See Hamermesh (1993) for a survey of empirical work examining capital-skill complementarity.

that capital-deepening, the diffusion of purchased electricity, and the introduction of continuous-process and batch methods of production greatly increased the relative demand for nonproduction workers and more-educated production workers in manufacturing from 1909 to 1929, but that wage differentials by skill did not increase during this period. They argue that the rapid increase in the supply of skills arising from the high school movement prevented wage inequality from rising in the face of what appears to be a skill-biased technological revolution. Thus, differential behavior of the rate of growth of the supply of skills or institutional changes may be able to account for the differential shifts in the wage structure in the 1980s versus the 1970s even if the skill-biased effect of technology did accelerate in the 1980s.

Further progress in evaluating the skill-biased technological change hypothesis for recent increases in U.S. wage inequality requires (1) using a framework that incorporates both shifts in the relative demand and relative supply of skills, (2) examining a sufficiently long time frame to determine whether factors viewed as important in the 1980s were absent in earlier periods with different wage structure behavior, and (3) looking at the relations among observable technology indicators and skill upgrading over such a longer time frame. We attempt such an assessment in this study.

Increased U.S. wage dispersion since 1979 has involved both a substantial rise in educational wage differentials and a large expansion of within-group (or residual) wage inequality. Relatively consistent information on relative earnings and quantities of workers by educational attainment is available since 1940. Thus we focus on the college/high school relative wage as a proxy for the relative price of "more-skilled" labor and study its relation to measured changes in the relative supply and implied changes in the relative demand for college-educated labor.[2]

We first present evidence on trends in the relative quantities, wages, and wage bill shares of workers by education in the aggregate U.S. labor market from 1940 to 1995. A simple relative supply and demand framework is used to interpret these data. The framework strongly suggests that the relative demand for more-skilled workers (college equivalents) grew more rapidly on average during the past twenty-five years (1970-95) than during the previous three decades (1940-70). In particular, it appears unambiguous that demand shifts favoring college workers were larger in the 1980s than in the 1960s. But conclusions concerning whether the rate of growth of relative demand for college workers began to accelerate in the 1980s or as early as the 1970s are sensitive to the specific approach used to measuring college-equivalent workers and the assumed value of the aggregate elasticity of substitution between college and non-college workers.

The acceleration in demand shifts for more-skilled workers in the 1970s and 1980s relative to the 1960s is *entirely* explained by within-industry changes in skill-utilization rather than between-industry employment shifts. A substantial increase in the rate of growth of the within-industry component of the relative demand for college workers from the 1960s to the 1970s is apparent throughout the economy, but a further sharp jump in the rate of the growth in utilization of college (and nonproduction) workers in the 1980s is only apparent in the

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[2]Although the college wage premium and within-group inequality move similarly during the 1980s, they are distinct outcomes and appear to have evolved differently in some earlier time periods. Researchers using March Current Population Survey (CPS) data find substantial decreases in the college wage premium and increases in within-group wage inequality during the 1970s (Juhn, Murphy and Pierce, 1993; Katz and Murphy, 1992). Those using the May Current Population Surveys find a similar decline in the college wage premium from 1973 to 1979 but only a modest increase or little change in within-group inequality (DiNardo, Fortin, and Lemieux, 1996; Mishel, Bernstein, and Schmitt, 1997).

manufacturing sector.

The diffusion of computers and related technologies may be sufficiently widespread to explain rapid within-industry skill upgrading in recent years. We next use data from the October 1984, 1989, and 1993 Current Population Survey (CPS) Supplements to document the growing utilization of computers in the work-place and find that the computer wage premium continued to grow from 1989 to 1993. We find that educational and occupational skill upgrading occurred more rapidly in industries with greater computer utilization in the 1980s and early 1990s. Measures of increases in the share of employees working with computers in the 1980s do not have much explanatory power for predicting which industries increased their pace of skill upgrading most rapidly from the 1970s to the 1980s, but they do help explain the pattern of skill upgrading in the post-1970 period relative to the 1960s. This evidence is suggestive of an acceleration in skill-biased technological change that started in the 1970s and was concentrated in the same sectors in the 1970s, 1980s and early 1990s.

We further explore the role of skill-biased technological change in the growth of the relative demand for more-skilled workers from 1960 to 1990 by linking data from multiple sources on industry work-force composition, physical capital intensity and the asset composition of capital stocks, research and development intensity, various measures of computer investments, and (for manufacturing industries) trade penetration and foreign outsourcing variables. We consistently find for both the manufacturing and non-manufacturing sectors that the increase in the rate of growth of the demand for more-educated workers is concentrated in the most computer-intensive industries and those industries with the most rapid growth in computer investments. Rising computer utilization and the growth of research and development expenditures as a fraction of sales appear to "explain" a substantially larger share of the rise in the rate of within-industry skill upgrading in U.S. manufacturing than does the growth of outsourcing or import competition.

II. THE RELATIVE SUPPLY OF AND DEMAND FOR SKILLS, 1940-95

To explore whether an explanation for the large expansion in U.S. educational wage differentials since the start of the 1980s requires an acceleration in the pace of relative demand shifts favoring more-skilled workers, we put the experience of the 1980s into a longer-term perspective. We examine changes in the relative quantities and wages of workers by education from 1940 to 1995, the longest time period for which appropriate data are available.[3]

We use the 1% Census Public Use Micro Samples (PUMSs) from 1940 to 1990 to measure changes in the college/high school wage differential and the educational attainment of the U.S. work force. The Census data are supplemented with data from the Current Population Survey (CPS) Merged Outgoing Rotation Group (MORG) files from 1980, 1990, and 1995. Because major changes in the educational attainment question were introduced in 1990 in the Census but not until 1992 in the Current Population Survey, we use consistent data on educational attainment from the 1980 and 1990 CPSs to measure changes from 1980 to 1990. Unfortunately the changes in the education question and the complete redesign of the CPS starting in 1994 mean there are even greater difficulties in measuring changes from 1990 to 1995. We present two estimates of 1990-95 changes using the 1995 MORG combined with either the 1990 Census PUMS or the February 1990 CPS since both of these 1990 samples use

[3]The 1940 Census of Population Public Use Micro Sample is the first nationally-representative sample with information on both educational attainment and earnings.

the new CPS education question. But all reported changes from 1990 to 1995 should be treated with caution given the lack of data comparability across these years. The Data Appendix provides details on the samples utilized.

Panel A of Table 1 shows the evolution of the educational composition of aggregate U.S. labor input (for those aged 18 to 65) measured in full-time equivalents (total hours worked) and of the log college/high school wage differential from 1940 to 1995.[4] (Appendix Table A1 presents the analogous trends in the educational composition of employment measured in bodies and of the total wage bill.) The educational attainment of the work force has increased rapidly throughout the fifty-five year period examined. Table 1 documents a dramatic decline in the share of those with less than a high school degree and a more than four-fold increase in the share of hours worked of college graduates and those with some college. Despite the continuing large increase in the relative supply of more-educated workers, the college/high school wage differential has grown substantially since 1950. Thus sharp secular increases in the relative demand for more-educated workers are essential to explain such a pattern in a supply-and-demand framework in which workers with different amounts of education are not perfect substitutes in production.[5]

Panel B of Table 1 displays annual rates of change in the relative earnings and quantity

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[4]The log college/high wage premiums presented in Table 1 are estimates of the log hourly wage differential for those with exactly 16 years of schooling relative to those with exactly 12 years of schooling.

[5]The large increases in the educational attainment of the U.S. work-force since 1940 may overstate increases in the relative supply of "more-skilled" workers to the extent that the "unobserved" quality of more-educated workers declines with some "re-labelling" of "lower productivity" workers into higher education categories. A careful study by Juhn, Kim, and Vella (1996) examines this issue using Census PUMS data from 1940 to 1990 and finds that conclusions concerning changes in relative supply and implied relative demand shifts are not much affected by adjustments for such re-labelling through controls for cohort-specific college share or mean years of education.

of college workers by decade. We summarize the relative quantity of labor by education by converting all workers into college and non-college workers.[6] We use two different classification schemes: (1) college graduates and all other workers; and (2) college equivalents (college graduates plus half of those with some college) and high school equivalents (half of those with some college plus workers with 12 or fewer years of schooling). The sharp compression of educational wage differentials in the 1940s followed by an expansion in the 1950s despite more rapid growth in the relative quantity of more-educated workers in the 1950s suggests an acceleration on the demand side in the 1950s and/or a large role of institutional factors in the 1940s (Goldin and Margo, 1992). In contrast, the large differences in changes in the college wage premium in the 1980s versus the 1970s may not require much change in demand behavior and could largely reflect sharp acceleration in the rate of growth of the relative supply of college workers (unadjusted for changes in demographic composition) in the 1970s with the baby boom cohorts combined with a deceleration in the 1980s and 1990s with the baby bust cohorts (Katz and Revenga, 1989; Katz and Murphy, 1992; and Murphy and Welch, 1992). But the larger increase in the college wage premium in the 1980s than in the 1960s does not appear likely to be attributable to supply growth differences and is suggestive of a recent acceleration in the relative demand for college workers (or important institutional wage structure changes in the 1980s such as the decline in unions and the real value of the minimum wage).

Table 2 attempts to more formally assess alternative relative supply and demand shift scenarios for the observed pattern of changes in the relative wages and relative quantities by

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[6]This two labor input framework clearly over-simplifies the analysis of relative wage determination, but it leads to broad conclusions that are similar to more disaggregated approaches such as used by Juhn (1994), Katz and Murphy (1992) and Murphy and Welch (1992). Johnson (1996) takes a similar approach to ours in defining college and high school equivalent workers.

education from 1940 to 1995. We use a simple two factor framework in which we assume an inelastic (predetermined) short run relative supply function and a downward sloping relative demand function. Information on changes in the log ratio of the wage bill of graduates to the wage bill of non-college workers and on changes in the (composition adjusted) relative wage of college graduates can be used to draw inferences concerning the rate of growth of the (composition adjusted) relative supply and the relative demand for college graduates across time periods. This point can be illustrated by considering a simple CES technology (aggregate production function) with two factors, college equivalents (c) and high school equivalents (h). Under the assumption that the economy operates on the labor demand curve, relative wages in year t, w_{ct}/w_{ht}, and relative supplies in year t, x_{ct}/x_{ht}, satisfy the relationship

(1) $$\log(w_{ct}/w_{ht}) = (1/\sigma)\,[D_t - \log(x_{ct}/x_{ht})]$$

where σ is the aggregate elasticity of substitution between college and high school equivalents and D_t indexes log relative demand shifts for college equivalents.[7] Solving equation (1) for D_t and rearranging terms yields

(2) $$D_t = \log([w_{ct}x_{ct}]/[w_{ht}x_t]) + (\sigma\text{-}1)\log(w_{ct}/w_{ht}).$$

[7]Since in reality there are other inputs in production, this is a conditional factor demand framework in which relative demand shifts are defined to include the effects of changes in the prices (or supplies) of other inputs such as capital and energy. The aggregate σ reflects not only substitution possibilities in firm-level production functions but also substitution possibilities across goods in consumption. Thus the aggregate σ will be larger than for a representative firm or industry.

Equation (2) implies that changes in the log relative demand for college equivalents equals the sum of the change in the log relative wage bill and a term that depends positively (negatively) on the change in the log college wage premium when $\sigma > 1$ ($\sigma < 1$). If $\sigma = 1$, then changes in the log relative demand for college equivalents are directly given by changes in the relative wage bill of college workers. Freeman (1986) shows that the most plausible early empirical estimates of the aggregate elasticity of substitution between highly educated and less educated workers in the United States tend to be between 0.5 and 2.5. More recent work by Katz and Murphy (1992) using U.S. annual time series information on relative wages and quantities of college- and high-school equivalents derived from the March CPSs for the 1963-87 period yields a point estimate of σ that is approximately 1.4, but they emphasize that substantial uncertainty exists concerning the magnitude of σ.

Panel A of Table 2 presents changes by decade in the log college wage premium as well as changes in the college/non-college log relative wage bill and (composition-adjusted) supply using both the college graduate and college equivalents aggregation schemes. The (composition-adjusted) log relative supply change is given by the log relative wage bill change minus the log relative wage change. The 1970s is the outlier decade in terms of relative supply growth. The rate of growth of the log relative supply of college workers accelerates dramatically in the 1970s and then decelerates substantially in the 1980s and 1990s under either classification scheme. The huge increase in the share of workers without college degrees but with some college education in the 1970s implies the jump in college relative supply growth from the 1960s to the 1970s is substantially larger under the college equivalents approach.[8]

The sensitivity of conclusions concerning the time path of the growth of the relative demand for college workers to assumptions about the magnitude of σ and the approach to defining skill groups is illustrated in panels B and C of Table 2.[9] The sharp contrast in the behavior of the college relative wage in the 1970s and 1980s can be attributed both to slower relative supply growth and faster relative demand growth in the 1980s under our preferred estimate of $\sigma=1.4$. But the deceleration of relative supply growth explains the majority of the difference in relative wage behavior between the 1970s and the 1980s for either skill aggregation method when σ is less than 2 or so. The implied acceleration in the pace of demand shifts in the 1980s relative to the 1970s is lower for smaller assumed values of σ and when one uses the college equivalents aggregation scheme. In fact, one can reach the conclusion that supply growth differences entirely explain differences in wage behavior in the 1970s versus the 1980s without resort to a new era of rapid skill-biased technological change for assumed values of σ from 0.5 to 1 (the low end of the range of existing estimates).

But our simple supply and demand framework does imply some far less ambiguous conclusions from Table 2, particularly concerning comparisons of the most recent twenty-five years to the preceding thirty years. First the rate of growth of the relative supply of college workers (both college graduates and college equivalents) was more rapid on average from 1970

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[8]The time pattern of relative supply growth is quite similar if one directly adjusts for compositional changes in the college and non-college groups by measuring employment in efficiency units in which hours worked are weighted by the average hourly wage of each individual's demographic group (e.g. age-sex-education group) in a base year (such as 1980). But this efficiency unit approach does suggest a modestly larger rate of growth of the relative supply of college graduates (and college equivalents) for the 1990 to 1995 period (and thereby implies a modestly larger rate of relative demand growth) than do the estimates in Table 2.

[9]The implied relative demand shifts are computed by plugging the data on changes in log relative wages and wage bills from panel A into equation (2).

to 1995 than from 1940 to 1970, but the college wage premium expanded in the later period and narrowed in the earlier period. This is clear evidence of an acceleration in the secular rate of growth of the relative demand for college workers with more rapid growth during the past twenty-five years (1970-95) than during the previous thirty years (1940-70).[10] Second the much greater increase in the college wage premium in the 1980s than in the 1960s appears to be driven by much faster relative demand growth in the 1980s. Third the growth of the relative demand for college workers seems to have slowed down some in the early 1990s versus its pace in the 1980s.

A conclusion that an increased pace of demand shifts favoring more-educated workers explains the secular rise in the college wage premium of college graduates over the past quarter century seems justified within a simple supply and demand framework for analyzing the labor market. Furthermore "consensus" estimates of σ for the aggregate economy of around 1.4 to 1.5 (Katz and Murphy, 1992; Johnson, 1996) imply a distinct increase in the rate of demand shifts favoring the more-skilled in the 1980s as suggested by the skill-biased technological change hypothesis for the recent rise in inequality. But differences in relative wage behavior between the 1980s and 1970s appear to be more affected by the differences in relative supply growth than differences in relative demand growth. Existing knowledge of the aggregate elasticity of substitution between college and non-college workers does not rule out scenarios in

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[10]The annualized percent change in the college/high school wage differential (measured in log points times 100) was 0.194 from 1970-95 and -0.167 from 1940-70. The relative supply of college workers increased by 0.63 percent more a year (using college graduates) and 0.92 percent more a year (using college equivalents) from 1970-95 than from 1940-70. Table 2 implies under the base-case assumption of $\sigma=1.4$ that the relative demand for college workers grew by over 1 percent (.01 log points) more a year from 1970-95 than from 1940-70 (i.e., the implied relative demand for college graduates grew 3.45 percent a year from 1970-95 versus 2.26 percent a year from 1940-70).

which a jump in relative demand growth occurred in the 1970s and the pace of relative demand growth did not further accelerate in the 1980s. Thus comparisons of skill-upgrading differences in the 1980s and 1960s might prove more fruitful than the usual focus solely on the 1980s or of limited comparisons of the 1980s and early 1990s to the 1970s.

Shift-Share Analysis

What factors explain the rapid shift of relative labor demand favoring more-educated workers? Explanations based on increased trade are likely to involve shifts in production from less-educated, import-intensive sectors to more-educated, export-intensive sectors. Broad skill-biased technological change and changes in the organization of work that favor more skilled-workers could operate by reducing the relative demand for less-educated workers within detailed industries. Alternatively the growth of the outsourcing of less-skill intensive tasks to low-wage nations could also generate substantial within-industry increases in the relative employment of more-educated workers in sectors that expanded such outsourcing activity.

A decomposition of the growth of the college graduate shares of employment and of the wage bill (shown in Appendix Table A1) into between- and within-industry components can help illustrate the potential importance of these alternative channels. A standard decomposition of the change in the proportion of group j (college graduates) in aggregate employment between years τ and t ($\Delta E_{jt} = E_{jt} - E_{j\tau}$) into a term reflecting the reallocation of employment across sectors and a term reflecting changes in proportions within industries is given by

$$(3) \qquad \Delta E_{jt} = \Sigma_k (\Delta E_{kt} \alpha_{jk.}) + \Sigma_k (\Delta \alpha_{jkt} E_{k.})$$

where k indexes industries, $\alpha_{jkt} = E_{jkt}/E_{kt}$ is the group j share of employment in industry k in year t, $\alpha_{jk.} = (\alpha_{jkt} + \alpha_{jk\tau})/2$, and $E_{k.} = (E_{kt} + E_{k\tau})/2$. The first term in (3) reflects the change in the aggregate proportion of college graduates attributable to changes in employment shares *between* industries that utilized different proportions of college graduates. The second term reflects *within-industry* skill upgrading. An analogous decomposition can be performed to analyze changes in the aggregate wage-bill share of college graduates.

Table 3 presents such between- and within-industry decompositions of the growth in the proportion of college graduates in employment and the college graduate wage bill share from 1960 to 1990 using 140 three-digit industries (made consistent among 1960, 1970, 1980, and 1990 Census Industry Codes). The between-industry components of the growth of the college employment and wage bill share are greatest in the 1960s mainly as a result of the rapid growth of the college-intensive education and public administration sectors. The acceleration in the growth of the employment and wage-bill shares of college graduates in the 1970s and 1980s relative to the 1960s is driven by within-industry increases.[11] The pattern is somewhat different in manufacturing and nonmanufacturing sectors. The within-industry growth in college wage bill share is faster in the 1970s and the 1980s than in the 1960s in both manufacturing and nonmanufacturing. The pace of within-sector college wage bill share growth is much higher in the 1980s than in the 1970s for manufacturing.[12] But, in contrast, the large acceleration in within-sector skill-upgrading occurs from the 1960s to the 1970s outside of manufacturing.

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[11] A similar pattern of acceleration in within-industry skill upgrading in the 1970s and 1980s versus the 1960s is apparent if one examines the labor input shares of our measure of college equivalents or of all workers with at least some college.

[12] Berman, Bound and Griliches (1994) reach a similar conclusion for the time pattern of within-industry growth of the nonproduction worker wage bill share in manufacturing.

The shift-share decompositions of the growth of the college wage-bill share can also be used to more directly measure the extent to which the growth in the relative demand for college workers has occurred within industries under the assumption that the within-industry elasticity of substitution between college and non-college workers equals 1.[13] Under this assumption the annual change in the within-industry log relative demand for college graduates for all industries is .0160 in the 1960s, .0298 in the 1970s, .0284 in the 1980s, and .0164 from 1990 to 1995 (using Census data for 1990 and CPS data for 1995). Thus the jump in the rate of growth of the relative demand for college labor from the 1960s to the 1970s and 1980s appears to be accounted for by a sharp increase in the rate of growth of relative skill demand occurring within three-digit industries.[14] The estimated rate of within-industry shifts in relative demand for workers returned to its 1960s historical level in the early 1990s.

The shift-share decompositions suggest the fruitfulness of searching for factors that could explain an acceleration in the within-sector demand for skills starting in the 1970s. Substantial differences in technology intensity and the pace of skill-upgrading across industries could provide

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[13]If equation (2) holds at the industry level with σ reinterpreted as the within-industry elasticity of substitution between college and non-college workers, then the within-industry growth in the log relative demand for college workers equals the growth in the log relative wage bill of college graduates when $\sigma=1$.

[14]These estimates are based on combining the within-industry component of college wage-bill share growth for all industries presented in panel B of Table 3 with information in Appendix Table 1 on the level of college wage-bill share at the start of each period. Let Y_c and Y_h equal the wage-bill shares for college graduates and non-college workers. If $\sigma=1$, then equation (2) implies the change in the log relative demand for college workers ($\Delta D_t = D_t - D_\tau$) can be written as:

$$\Delta D_t = \Delta\log(Y_{ct}/Y_{ht}) = \log(1 + [\Delta Y_{ct}/Y_{c\tau}]) - \log(1 + [\Delta Y_{ht}/Y_{h\tau}]).$$

Thus the within-industry log relative demand change for college workers is given by

$$\Delta D_t^w = \log(1 + [\Delta Y_{ct}^w/Y_{c\tau}]) - \log(1 + [\Delta Y_{ht}^w/Y_{h\tau}]),$$

where $\Delta Y_{ct}^w = -\Delta Y_{ht}^w =$ the within-industry component of college wage-bill share growth given by a modified version of equation (3) with the wage bill replacing employment.

a means of assessing the importance of observable proxies for technological change in the increased rate of growth of the relative demand for college graduates.

III. TRENDS IN COMPUTER TECHNOLOGY

The diffusion of computers and related technologies is a prime suspect for a widespread recent technological change that could lead to major changes in the demand for skill within industries and firms. Computer technology has influenced work-place equipment and practices in several ways.[15] Although computer technology dates back to at least the 1940s, microprocessors first were introduced on a wide scale in manufacturing machinery in the 1970s. Mainframe computing equipment also became more commonplace in the service sector in the 1970s. With the birth of the Apple II in 1977 and the IBM PC in 1981, personal computers spread rapidly in the 1980s and early 1990s.

One approach to measuring the spread of computer technology is by the fraction of workers who directly use a computer keyboard. Although this approach misses workers who use devices with embedded microprocessors not operated by keyboards, it measures a particularly prevalent form of computer technology. Table 4 reports the percentage of workers who report using a computer keyboard at work in selected years. The table is based on data from the CPS for October 1984, 1989, and 1993. The prevalence of computer use at work increased almost linearly from one-quarter of the work force in 1984, to over one-third in 1989, and to nearly one-half in 1993 -- an average increase of 2.4 percent of the workforce per year. Comparable data are not available for earlier years, but computer use at work is likely to have

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[15] See Levy and Murnane (1996) for a case study of this process in action in the financial services industry.

been prevalent since the mid-1970s, as mainframe and early desktop machines were available.

The growth in computer use since 1984 has not been uniform across demographic groups. Notably, Table 4 shows that women, more highly-educated workers, whites, white-collar workers, and full-time workers are more likely to use computers. In general, the groups that experienced the greatest increases in computer use between 1984 and 1993 are also more likely to have experienced relative wage gains. Appendix Table A2 reports the extent of computer use in 1984, and growth in computer use between 1984 and 1993, for 140 (approximate three-digit) industry groups. Computer use has become especially prevalent in such industries as legal services, dairy products, advertising and public administration, while remaining unsurprisingly relatively rare in logging, taxicab services, beauty shops, barber shops, and bowling alleys.

Table 5 updates some of the descriptive wage regressions in Krueger (1993). As computer technology spread between 1984 and 1993, the "premium" associated with using a computer at work increased from 17 log points to 20 log points. Whether the computer premium estimated in this fashion represents a true return to computer skills or omitted characteristics of workers and their employers is currently the subject of some controversy (see, for example, Bell (1996) and DiNardo and Pischke (1997)).

Comparing the 1984-93 increase in the coefficient on education from the model estimated in column (1) with the corresponding increase from the model estimated in column (2) -- which controls for the effect of computer use -- suggests that holding constant the effect of computer use accounts for some 35% of the rise in the return to education. The model in column (3) includes an interaction between education and computer use. The coefficient on this interaction term has increased over time. Columns (4) and (5) include dummy variables indicating college attainment, some college, and less than high school education rather than a linear education variable. The omitted education group is exactly high school graduates. These results indicate that the college-high school earnings premium increased by 11.3 log points between 1983 and 1993, while for non-computer users it only increased by 3.6 points.

Rather than trying to determine with cross-section data whether the estimated 17-20 percent computer wage premium is an unbiased estimate of the payoff to computer skills, we next focus on examining whether the spread of computers is associated with increases in the relative demand for highly educated labor.[16]

IV. EVIDENCE ON COMPUTERS AND SKILL UPGRADING, 1960-95

Most of the rise in the employment and wage-bill shares of college graduates since 1970 has occurred within detailed industries. To better understand the determinants of within-industry shifts toward more highly educated workers, we relate the change in the share of workers in each educational group across industries to industry-level measures of the utilization of computers. Table 6 presents results for the 1979-93 period. The dependent variable is the annualized change in the fraction of workers employed in each education group between 1979 and 1993, calculated from the MORG files of the CPS. The main explanatory variable is the annualized change in the fraction of workers in the industry who used a computer, based on the

[16] The existence of a positive computer wage differential is neither a necessary nor a sufficient condition for the diffusion of computers to have induced a shift in the relative demand for more-skilled workers and to have affected the wage structure. If computer technologies are more complementary with highly-skilled than less-skilled workers, a decline in computing costs and spread of computers could generate an increase in the relative demand for and relative wages of more-educated (and more-skilled) workers. Labor market competition could require firms both with and without computer technologies to pay equal wages to attain equally able employees. In this case a cross-section wage regression with sufficient controls for worker skills would yield no computer wage premium even though computers may have greatly raised the relative wages of the more-skilled and widened the wage structure.

1984 and 1993 October CPS's. The results indicate that the shift toward college-educated workers, and away from high-school educated workers, was greatest in industries that experienced the greatest increase in computer use. This pattern is quite similar for men and women.

The magnitude of the coefficient on computer use implies that the growth of computers at work can account for a large share of the growth of college-educated employment. Between 1979 and 1993, college-educated workers' share of employment increased by .36 percentage points per year. The intercept of the bivariate regression in the first column however, is just .03, which implies that at a constant level of computer use one would predict hardly any increase in the share of college-educated employment over this period. More rapid growth of computer use is also negatively related to the change in the share of those with exactly high school degrees in industry employment. The contrasting relations of change in computer use from 1984 to 1993 with changes in the employment shares of college and high school graduates from 1979 to 1993 are illustrated in Figures 1(a) and 1(b).

Faster growth in computers is surprisingly associated with a relative rise in the share of less-than-high school workers in an industry. This finding results in large part because industries that saw the greatest growth in computer use employed relatively few high school dropouts to start with, and employment of less-than-high school educated workers fell substantially in almost all industries during this period. There is a limit to how much the share of high-school dropouts can fall in high-tech industries that initially employed very few high school dropouts. When the average years of education in an industry (measured in 1974 to avoid a mechanical correlation) is controlled in the right-hand part of Table 6, the growth of computer use across industries has an insignificant effect on the employment share of less-than-high school workers, but continues to have a strong positive effect on employment of college graduates and a strong negative effect on employment of high school graduates.

Three robustness checks are worth reporting. First, similar results are obtained if each educational group's share of hours or of payroll is used as the dependent variable. Second, the growth in computer use is not perfectly aligned with the dependent variable in Table 5 because data on the fraction of workers who use a computer are not available prior to 1984. If the dependent variable is based on the 1984-93 change in employment shares, however, the results are qualitatively similar. Moreover, if we assume that all industries started from a base of zero computer use in 1979 (which is clearly an exaggeration), the growth in computer use from 1979-93 has a similar effect.

Finally, as another measure of employee skill, we have done a similar analysis using industry-level data to relate the annualized change in the proportion of workers in each *major occupational category* between 1979 and 1993 to the annualized change in the fraction of workers in the industry who use a computer. Consistent with the educational upgrading patterns, these results indicate that industries that experienced the greatest growth in computer use tended to shift their occupational mix toward managers and professionals, and away from administrative support/clerical and service workers. In general, occupations with higher average pay and higher education tended to expand in sectors that adopted computer technology at a faster rate.

<u>1960-1995 Results</u>

A concern with the regression results in Table 6 is that they may spuriously reflect past trends in skill upgrading, rather than a discrete break from pre-existing trends. Furthermore, causality could be reversed -- hiring more educated workers may lead an industry to subsequently adopt computer technology, rather than vice versa (Doms, Dunne, and Troske, 1997). To explore these possibilities, we use Census and CPS data to look at each decade since 1960 and at the 1990 to 1995 period. If the post-1979 shift toward more highly educated workers in industries that greatly expanded computer use spuriously reflects a continuation of earlier trends in skill upgrading, then we would expect to see a similar employment shift in the 1960s, prior to the computer revolution at work.

Table 7 reports estimates of the same type of models in Table 6, only now we relate the annualized change in the *share of payroll* due to college-educated workers in each industry to the 1984-93 change in the fraction of workers in the industry who use a computer.[17] (Estimates for comparable models that use the annualized change in college-educated-workers' share of employment as the dependent variable are presented in Appendix Table 3.) Notably, in the 1960-70 period, inter-industry changes in the wage-bill share of college-educated workers are weakly related to the subsequent increase in computer use in the industry. During the 1970-80, 1980-90, and 1990-95 periods, however, a stronger relationship between the shift toward college-educated workers and computer adoption (in the 1984-93 period) is apparent. Moreover, the coefficient relating the change in the wage-bill-share of college-educated workers and computer adoption is roughly of the same magnitude in the 1970s and 1980s. These findings

[17]In the remainder of this study, we focus on changes in the college wage-bill share as our primary measure of within-industry skill-upgrading, both for comparability with the specifications used in previous work (e.g., Berman, Bound, and Griliches (1994); and Machin, Ryan, and Van Reenen (1996)) and because, as equation (2) illustrates, the change in an industry's relative wage bill share of college workers is a close proxy for the growth in its relative demand for college workers if the elasticity of substitution between college and non-college workers at the industry level is close to 1.

suggest that an acceleration of the pace of skill upgrading concentrated in computer-intensive sectors occurred during the 1970s and was followed by a continuation of within-industry shifts towards college workers at a similar rapid rate during the 1980s. This timing coincides with the predictions of our simple supply and demand framework under the assumption the aggregate elasticity of substitution between college and non-college workers is not too high.

The magnitude of the computer-use coefficients and changes in computer-use over these periods can account for a substantial increase in the share of payroll devoted to college-educated workers. Between 1980 and 1990, for example, the share of payroll going to college graduates increased by .61 percentage points annually (see weighted average at the bottom of Table 7). But the intercept in the bivariate regression in column 1 suggests that for an industry with constant computer use the increase is just .29 percentage points, so just over half of the annual increase in payroll going to college graduates is "accounted for" by the spread of computer use. A similar calculation for the 1970s also indicates that the spread of computers can account for about half of the increased percentage of payroll going to college graduates. Between the 1960s and the 1970s, the growth in the fraction of payroll going to college graduates increased by .32 percentage points per year, whereas the increase is predicted to be .19 percentage points in sectors with no growth in computer use from 1984 to 1993; thus, computers may account for nearly 40 percent of the acceleration in the shift of payroll toward college graduates between the 1960s and 1970s. An analogous calculation suggests that the spread in computers can account for almost half of the acceleration between the 1960s and 1980s. Lastly, we note that somewhat larger effects are estimated if the share of college-educated employment (as opposed to payroll) is used as the dependent variable (see Appendix Table 3).

V. COMPUTERS, CAPITAL INTENSITY, R&D, AND SKILL UPGRADING

We next examine whether the strong positive relation between computer usage and educational upgrading reflects factors possibly specific to computers and other high-technology investments, or broader patterns of capital-skill complementarity. To perform such an exercise, one must combine data on the educational attainment of industry work-forces with data on the level and composition of each industry's physical capital stock. As described in the Data Appendix, we link data on educational shares of industry employment and wage bills from our Census and CPS samples with National Income and Product Account (NIPA) data on industry capital stocks, investment, and full time equivalent employees (FTEEs). Data from the CPS and Census are matched to NIPA data in 47 aggregated (approximate two-digit) industries covering all private industry sectors (except for private household services).

The NIPA data provide information on overall capital intensity and multiple potential measures of "high-tech" capital intensity. The closest measure to our CPS measure of computer utilization is the stock of office computing and accounting machinery (OCAM) per worker.[18] Berndt, Morrison, and Rosenblum (1992) define a broader measure of high-tech capital as the sum of the real net stocks of OCAM, scientific and engineering equipment, communications equipment, and photocopy equipment.[19] NIPA capital stock data by asset category for detailed industries are based upon many imputations and are likely to be measured with substantial error

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[18]The across-industry correlation (weighted by each industry's wage bill) of OCAM per FTEE in 1980 and the proportion of workers using computers in 1984 is 0.74; the analogous correlation for OCAM per worker in 1990 and CPS computer utilization in 1989 is 0.77. The 1980-90 change in OCAM per FTEE has a (weighted) correlation of 0.47 with the change in computer usage from 1984 to 1993.

[19]Allen (1996) focuses on a narrower measure of high-tech capital (OCAM plus scientific and engineering instruments) and finds a positive cross-industry relationship between changes in high-tech capital per worker in the 1980s and changes in the employment share of college graduates.

(Berndt and Morrison, 1995). Industry investment in many specific asset categories (such as OCAM) is not directly measured (at least at high frequency) by the Bureau of Economic Analysis (BEA), but is allocated across industries using capital flow tables and other "indicators" assumed to be correlated with industry commodity use (such as employment), and then further adjusted to match control totals from other reference sources (cf., Gorman et al., 1985).[20] Since industry occupational distributions may be used as "indicators" in the allocation of some capital assets, the possibility exists for some mechanical contemporaneous correlation between imputed OCAM investment and industry skill upgrading. Thus we focus on the relationship between lagged measures of OCAM capital stocks per workers and skill upgrading rather than contemporaneous correlations. Despite these measurement problems, the NIPA data are the best available source of information on "high-tech" capital and overall capital intensity outside of the manufacturing sector.

Because the NIPA data only include private sector capital, we focus our empirical analysis of educational upgrading on 41 non-agricultural industries excluding service-sector aggregates with substantial government employment (e.g., health services and educational services).[21] Trends in the levels and log growth rates of OCAM as a share of the capital stock, OCAM per worker, and overall capital intensity for these industries are illustrated in Appendix Table 4. The rate of growth of the aggregate capital/labor ratio decelerated from the 1960s to

[20]Circa 1985, 12 percent of the value of structures and 67 percent of the value of equipment was allocated according to indicators (Silverstein, 1985).

[21]We also exclude the "Nonmetallic minerals, except fuels" sector from the regressions reported in this section since its low level of computer (office, computing, and accounting machine) capital makes it an extreme outlier. The findings in Table 8 are quite similar when this sector as well as the agricultural and other service industries are kept in the sample.

the 1970s and then decelerated further in the 1980s, but this phenomenon is much more pronounced in non-manufacturing industries. This time pattern of growth in the capital stock suggest that overall changes in capital intensity are unlikely to be able to explain the observed acceleration in the pace of skill upgrading in the 1980s. But changes in technology and the composition of the capital stock (e.g., towards computers and computer-related technologies) which may increase the degree of complementarity between capital and skilled workers could play a role. While OCAM per worker is relatively stable from 1960 to 1970, it increases dramatically with the computer revolution of the 1970s and the 1980s.

Table 8 presents a set of pooled cross-industry regressions covering 1960-70, 1970-80, and 1980-90 of changes in the college graduate share of the wage bill on indicators of computer (OCAM) capital intensity and changes in overall capital intensity. Column (1) includes only time dummies for the 1970-80 and 1980-90 periods and illustrates an acceleration in the within-industry growth of the college wage bill share in the 1970s and 1980s. Column (2) shows a strong positive relationship between the log of an industry's computer capital (OCAM) per FTEE at the start of each decade and that industry's growth of the college wage bill share over the next ten years. The growth of computer capital per worker can account for the acceleration in the growth rate of the college wage-bill share from the 1970s to the 1980s and can "explain" 40 percent of the difference in the rate of increase in the 1980s and the 1960s. The impact of computer capital is not substantially affected when the change in the log capital-labor ratio is added to the regression in column (3). Similar findings appear in the next column which includes the change in the log capital/output ratio and the growth rate of real output.[22] (But the positive coefficients on the change in the log capital/labor and log capital/output ratios in columns (3) and (4) are consistent with much existing empirical work indicating overall capital-skill complementarity.) Finally column (5) indicates that it is the initial stock of computer capital (possibly picking up the effects of lagged investments) rather than the contemporaneous change in computer capital that is most strongly related to growth in the college wage-bill share.[23] Columns (6) and (7) show the impact on the growth of the college wage-bill share of computer capital per FTEE are close to identical in the manufacturing and non-manufacturing sectors. But changes in overall capital intensity are much more important in the skill-upgrading process in the manufacturing sector. We have performed multiple robustness checks of these findings. The results are almost identical when the total capital stock is replaced with the total stock of equipment in the specifications in columns (3) to (5). The impacts of OCAM capital on skill upgrading are much stronger than those of other components of the high-tech capital. If one interacts the lagged computer capital stock per FTEE variable, the coefficient is somewhat larger in the 1980s. Furthermore, the findings are similar when the change in college employment share is used as the dependent variable.

We also employ research and development (R&D) expenditures as a percentage of sales, tabulated by the National Science Foundation (NSF), as a technology indicator. As described

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[22]Thus column (4) adds the OCAM variable to the basic specification for the share in total variable costs (total labor costs) of a variable input (college labor) when the cost function takes on a translog form and capital is treated as a quasi-fixed input (e.g., Berman, Bound, and Griliches (1994)).

[23]Column (5) offers some evidence against a mechanical relationship between OCAM and the dependent variable. If the OCAM measure merely reflected the industry occupational distribution, *changes* in OCAM should be highly correlated with industry skill upgrading assuming that upgrading occurs in part via changes in the occupational distribution (a pattern which our CPS data confirm).

in the Data Appendix, we further aggregate the NIPA industries to incorporate the NSF industry classification, leaving 14 manufacturing industries excluding Miscellaneous Manufacturing (an unstable composite). The weighted mean of R&D doubles between 1960 and 1990, increasing from 1.72 percent of sales in 1960 to 2.12 percent in 1970, 2.71 percent in 1980, and 3.54 percent in 1990.[24]

Table 9 presents pooled industry college wage-bill share growth regressions for the 1960–70, 1970–80, and 1980-90 periods limited to the 14 manufacturing sector aggregates and incorporating the R&D data. For comparison to column (6) of Table 8, column (1) of Table 9 presents a regression of the growth in the college wage-bill share on OCAM, the capital/labor ratio, and time dummies. Despite aggregation, all coefficients are closely comparable to the earlier table. Column (2), which adds lagged R&D investment, indicates that R&D has a significant impact on skill upgrading. Additionally, the inclusion of R&D reduces the OCAM coefficient, but it does not substantially reduce the unexplained acceleration in skill-upgrading in the 1980s relative to the 1970s and 1960s.[25] The estimates in column (3) also imply that the mean increase in R&D over sales from 1970 to 1980 accounts for a .047 percentage point a year increase in the growth of the college graduate share of payroll in the 1980s relative to the 1970s. This R&D effect is about half as large as the implied contribution to the acceleration of skill upgrading in the 1980s of OCAM.

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[24]The (wage-bill share) weighted correlation between OCAM and R&D is .33 in 1960, .56 in 1970, and .69 in 1980.

[25]The column (2) estimate of R&D's impact on skill upgrading is closely comparable to that found by Berman, Bound, and Griliches (1994) using data on four-digit manufacturing industries for the 1979-1987 period. Machin, Ryan, and Van Reenen (1996) also find substantial positive effects of lagged R&D expenditures on the growth of "high skill" employment and wage bill shares using higher frequency industry-level panel data for the United States, United Kingdom, Denmark, and Sweden.

By removing the constraint that the marginal R&D impact is constant over time in column (3), however, we find that the effect of the level in R&D spending on skill upgrading is significantly greater in the 1980s than in the 1970s or 1960s. The difference in the mean R&D impact on skill upgrading in the 1980s and the 1960s can account for a .39 percentage point a year acceleration in the rate of growth of the college wage bill share from the 1960s to the 1980s (or 70 percent of the overall acceleration).[26] Column (4) replaces R&D with industry average computer use in 1984 (from the Current Population Survey) interacted with time dummies. The computer use effect in the 1980s is also significantly greater than in previous decades, though this could reflect the impact of measurement error since our CPS measure is only contemporaneous with the 1980 data. The changing coefficient on employee computer use in 1984 can account for most of the acceleration in the 1980s, and the inclusion of the CPS computer variable reduces the lagged OCAM capital per worker measure to statistical insignificance. Adding R&D to this model, as in specification (5), only slightly reduces the estimated impact of computer use on skill upgrading, whereas the R&D coefficient is now insignificant.[27] Finally, column (6) incorporates both computer use and R&D in time-interacted form and similarly implies that the computer use and R&D proxies "explain" most of the acceleration in skill upgrading in the 1980s.[28]

We next turn to a more detailed examination of skill-upgrading (the shift towards

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[26]The mean R&D impact in each decade is the product of that decade's R&D coefficient in column (3) and the weighted mean of R&D as a percentage of sales at the start of the decade.

[27]The weighted correlation between computer use in 1984 and R&D in 1980 is .83.

[28]The estimates in Table 9 are quite robust to the choice of dependent variable (wage-bill or employment share), the use of weights, and the exclusion of high-leverage observations.

nonproduction workers) in the manufacturing sector.

VI. SKILL UPGRADING IN DETAILED MANUFACTURING INDUSTRIES REVISITED

In addition to skill-biased technological change, increased import competition and outsourcing have been offered as explanations for the sharp acceleration in the rate of skill upgrading found in the U.S. manufacturing sector in the 1980s. Data for more disaggregated industries on the skill composition of the work-force and indicators of technological change, international competition, and outsourcing are available in the manufacturing than in the nonmanufacturing sector. We use data on 450 four-digit industries from the NBER Productivity Database (described in Bartelsman and Gray (1996)) for the 1959 to 1989 period to re-examine these alternative hypotheses. Information on the educational attainment of the work-force is not available at the four-digit industry level so we follow Berman, Bound, and Griliches (1994) and others in using the change in the nonproduction worker share of the wage bill as our measure of skill upgrading. The annual percentage point change in the nonproduction worker share of the total manufacturing wage bill increased from .110 for 1959-69 to .126 for 1969-79, and then shot up to .375 for 1979-89.

Berman, Bound, and Griliches (1994) find in cross-industry regressions that the growth of the nonproduction worker wage-bill share from 1979 to 1987 is strongly positively related to computer investments as a share of total investment and to R&D over sales. But they do not examine whether the growth of R&D and computer investments can account for the acceleration in within-sector growth of nonproduction worker share of payroll from the 1970s to the 1980s. Feenstra and Hanson (1996) present evidence that the growth of outsourcing of parts of domestic production to foreign suppliers (measured as the share of imported inputs in total non-energy material purchases) played some role in the increase of the pace of skill upgrading in the 1980s, but they do not compare the explanatory power of outsourcing with that of computer investments. To more thoroughly assess the possible factors behind the time pattern of increases in the utilization of more-skilled workers in manufacturing, we link data on the change in nonproduction worker wage bill share, changes in capital intensity, real shipments growth, and total factor productivity growth from the NBER Productivity sample with information on computer investments as a share of total investments from the Census of Manufactures, import and export penetration measures from Feenstra (1996), and the outsourcing measure used by Feenstra and Hanson (1996).

The first six columns of Table 10 present a set of pooled cross-industry regressions covering 1959-69, 1969-79, and 1979-89 attempting to explain changes in the nonproduction worker wage-bill share.[29] Column (1) documents the sharp increase in the rate of within-industry growth of nonproduction worker payroll share in the 1980s. Column (2) includes the computer investment variable and indicates that the growth of the mean computer investment share from .026 in the 1970s to .057 in the 1980s can account for a rise of .09 percentage points annually (or 36 percent of the total increase) in the rate of skill upgrading from the 1970s to the 1980s. The impact of computer investments is little changed when measures of overall capital intensity and output growth are included as in column (4). The estimates in column (3) show a significant effect of outsourcing on skill upgrading when no other covariates but time dummies are included. But column (5) shows that the computer investment impact on skill upgrading is

[29]These particular years were chosen because they occur at reasonably similar points in the business cycle.

much more robust to the inclusion of further covariates than is the outsourcing effect. Neither total factor productivity growth nor changes in import share appear significantly related to the growth of nonproduction worker payroll share once computer investment is included in the specification. The overall growth of the log capital-output ratio and growth in the exports-to-shipments ratios are both positively and significantly related to skill upgrading in the pooled model displayed in column (5). Furthermore the effect of computer investment on skill upgrading is quite similar when the specifications reported in columns (2), (4), (5), and (6) are expanded to include four-digit industry fixed effects.

Columns (7), (8), and (9) of Table 10 remove the constraint that the coefficients are the same across decades and present separate regressions by decade analogous to the pooled specification in column (6). Computer investment remains a powerful explanatory variable in all three decades. The coefficient on overall capital intensity increases over time, suggesting a possible secular rise in the magnitude of capital-skill complementarity in U.S. manufacturing from the 1960s to the 1980s. But outsourcing has a statistically insignificant effect on the growth of nonproduction worker wage-bill share in all three decades when the computer investment variable is included.

In summary, the estimates in Table 10 indicate that the growth in the computer investment ratio can explain approximately one-third of the acceleration in within-industry skill upgrading in U.S. manufacturing from the 1970s to the 1980s. Changes in import penetration and outsourcing explain very little of the increase in the rate of skill upgrading. Export-intensive sectors appear to have faster growth in nonproduction worker wage-bill share, but the growth of exports is not very important in the rise of the rate of skill upgrading across decades.

VII. CONCLUSIONS

Studies of the role of skill-biased technological change in the recent widening of the U.S. wage structure need to take a longer-term perspective than just the last fifteen years or even a comparison of the 1980s to the 1970s. An analysis of the time pattern of aggregate changes in the relative supply, relative price, and relative wage-bill share of college graduates over the 1940 to 1995 period suggests that the relative demand for more-skilled workers (college equivalents) grew more rapidly on average during the past twenty-five years (1970-95) than during the previous three decades (1940-70). In particular, the rate of growth of the relative demand for more-educated workers appears to have been more rapid in the 1970s and 1980s than in the 1960s. But the common view that the demand for more-skilled workers greatly accelerated in the 1980s relative to the 1970s is not unambiguously supported by such an analysis. The acceleration appears to have begun in the 1970s, but its effects on educational and occupational wage differentials did not show up until the growth rate of the supply of college graduates slowed at the beginning of the 1980s. Furthermore the acceleration in demand shifts for more-skilled workers since 1970 is entirely driven by more rapid within-industry changes in skill-utilization rather than between-industry employment shifts.

Indicators of computer usage, computer capital per worker, and computer investment as a share of total investment are higher in industries with larger accelerations in skill upgrading in the 1970s and 1980s versus the 1960s than in industries with little or no such acceleration. Our results suggest that the spread of computer technology may "explain" as much as 30 to 50 percent of the increase in the rate of growth of the wage-bill share of more-skilled workers since 1970. The growth of computer investments also appears to account for over 30 percent of the large increase in the rate of within-industry skill upgrading found in detailed U.S. manufacturing industries during the 1980s. Although these conditional correlations of computer measures and the growth in the utilization of college workers and nonproduction workers may not reflect causal relationships, it is clear that whatever is driving increases in the rate of growth of demand for skilled labor over the past twenty-five years is concentrated in the most computer-intensive sectors of the U.S. economy.

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Data Appendix

Computer use in the Current Population Survey

In October 1984, 1989, and 1993, as part of the School Enrollment Supplement to the Current Population Survey (CPS), interviewees were asked a number of questions about their computer use at home and at work. In particular, the survey asked "Do you use a computer directly at work?" to which respondents answered yes or no. In the CPS questionnaire, a computer is defined as a desktop terminal or PC with keyboard and monitor. Those using an electronic cash register or a hand held data device (for example, a package tracking computer used by a delivery driver) would be instructed to answer no to the CPS computer use question. After limiting the sample to those ages 18-65 who were working in the week prior to the survey (or, with job but not at work), the responses to this question (62,005, 63,085 and 60,156 in 1984, 1989, and 1993 respectively) provide a representative and well-defined measure of the level of workplace computer use in the U.S. economy. Using this measure, we tabulated the weighted mean frequency of computer use in each industry cell within consistent Census Industry Code (CIC) industries (see below) in 1984, 1989, and 1993.

Samples Used from the CPS and the Census

CPS. To calculate educational employment shares, educational full-time employment equivalent (FTE) shares, and educational wage bill shares, we used the Merged Outgoing Rotation Group (MORG) files of the Current Population Survey for the years 1980, 1990, and 1995. In addition, we analyzed the February 1990 CPS which contains educational attainment questions corresponding to both the old and new standard (see below). Samples were limited to those currently employed in the sample reference week, excluding those working without pay. Self-employed workers were retained in the sample. Top-coded earnings observations were multiplied by 1.5. The cross-sectional log wage regressions used to calculate the college/high premiums reported in Tables 1 and 2 are further limited to wage and salary workers earning between $0.50 and $250 per hour in 1990 dollars. We use the CPI urban deflator to calculate these intervals in each year.

Educational employment shares by industry were calculated as the fraction of workers in each of four educational categories (less than high school, high school, some college, and college plus) employed in each industry. We calculated the share of total hours supplied by each education category in each industry as the sum of usual weekly hours reported by each worker in each education category divided by the total hours reported in that industry. Because self-employed workers do not report hours (or earnings), we assigned them the average labor hours in their industry-education-year cell. In several small industries, average hours supplied by education category were unavailable (as for example in CIC 790, Dressmaking Shops, where all sampled workers with high school education or less were self-employed). In these cases, we imputed weekly hours as 40 per worker. Calculations were performed using CPS final weights.

To calculate wage bill shares, we performed an analogous procedure, calculating sums of weekly earnings by industry-education cell and dividing by total weekly earnings in each industry. Because the self-employed do not report weekly earnings, we assigned them the mean earnings in their industry-education-year cell. In the few industries where earnings were missing in some education cells (again, due to the fact that self-employed workers do not report usual weekly earnings), we assigned the mean overall wage for the given education groups and years to the empty industry-education-year cells. All calculations use

CPS final weights.

Because changes to the earnings questions in the revised Current Population Survey (starting in 1994) significantly distort the wages of workers with low weekly hours,[1] we assigned those workers in 1995 with fewer than 8 weekly hours the mean wage for other part-time workers (those with 8-35 weekly hours) in the same industry-education-year-cell. The log earnings regressions used to calculate the college/high school wage premiums in Tables 1 and 2 use only the wages of full-time workers in our sample in 1995 and, for comparability, in 1990.

In addition to the surveys mentioned above, Table 6 (estimates of the relationship between computerization and educational upgrading) use the CPS MORG files from 1979 and 1993. The sample criteria used are identical to those above except that self-employed workers were excluded. To calculate lagged industry educational levels from 1974, we used the 1974 May CPS file.

For the cross-section estimates in Table 5, we followed Krueger (1993). The sample was limited to wage & salary workers between the ages of 16 - 64 who were working the previous week (or with job but not at work). Those with usual hourly wages less than $1.50 or greater than $250 per hour were dropped. In 1989 and 1993, no correction was made for topcoding because the topcode of $1923 per week affected very few workers. For 1984, workers who were topcoded (at $999) were assigned the deflated mean log hourly wage of individuals who in 1989 had weekly earnings greater than or equal to $999.

Census. For decade-to-decade educational share, FTE, and wage bill share models, we used the 1% Census Public Use Micro-Samples (PUMS) for 1940, 1950, 1960, 1970, 1980, and 1990. In all cases, we limited the sample to workers currently employed during the survey reference week between ages 18-65 inclusive. Workers who worked without pay were excluded from the sample, while the self-employed were retained. We calculated education shares, FTE shares, and wage bill shares by education group in a manner identical to that described above, with the exception that FTEs were not imputed to any observations.[2] We calculated hourly wages as the ratio of wage and salary earnings in the previous year to the product of weeks worked in the previous year and hours worked in the previous week. Wages were imputed to the currently self-employed and those with missing income as described above. Although usual hours in the previous year (as opposed to the survey reference week) were available in some Census samples, for consistency we used hours worked in the previous week to calculate wages in all samples. Top coded income observations were multiplied by 1.5 in each year. Because, in 1990, Census income top-codes varied by state (but were always at or above 140,000), we

[1] The revised CPS questionnaire takes pains to elicit reporting of even small numbers of hours worked by part-time workers. Since hourly wages are calculated as the ratio of weekly earnings to weekly hours, any misreporting of weekly hours by low-hours workers has an asymmetric effect on average part-time wages: in cases where reported hours are less than true hours (due to sampling error or rounding), the implied wage tends to infinity as the reported hours (the denominator) tend towards zero. Empirically, we find that the uncorrected mean part-time wage increases from $8.43 in 1993 to $16.28 in 1994 (the first year of the revised survey). To circumvent this part-time wage inflation, we imputed the wages of low-hours workers as described above. The authors thank Douglas Staiger for his insights into this point.

[2] Hours worked are reported for all respondents in the Census, including the self-employed.

assigned top-coded observations the value of 210,000 (i.e., 140,000 multiplied by 1.5). Because both weeks-worked and hours-worked variables are intervalled in 1960, we used the mid-point of each interval in lieu of the actual value.

Changes to the coding of the educational variable after 1990 in the Census and CPS.

Prior to 1990 in the Census and prior to 1992 in the CPS, the Census and CPS provided measures of educational attainment based on answers to a question on highest grade attended and whether that grade was completed. Beginning with the 1990 Census and the 1992 CPS, the Bureau of the Census switched to a format which records workers' highest degree held or, when no degree is held, whether the highest grade attained falls within certain multi-year categories. This change creates non-trivial incompatibilities in comparing educational levels between CPS or Census samples before and after the change. As is documented in Frazis, Ports, and Stewart (1995), approximately 15 percent of those with 12 completed years of schooling in 1990 did not hold a high school degree while 10 percent of those with 16 years of completed education did not hold a college degree. As a result, when categorizing workers into the four education groups using the new question, we find a substantial (and implausible) drop-off in the workforce share of high school graduates and an even larger gain in the workforce share of those with some college.

Following the recommendations of Jaeger (1995), we use the following educational groupings. In data coded with the old education question (Census PUMS 1940, 1950, 1960, 1970, and 1980, and CPS MORG files 1980 and 1990), we defined high school dropouts as those with fewer than 12 years of completed schooling; high school graduates as those having 12 years of completed schooling; some college attendees as those with any schooling beyond 12 years (completed or not) and less than 16 completed years; and college graduates as those with 16 or more years of completed schooling. In data coded with the new question (1990 Census PUMS, February 1990 CPS, 1995 CPS MORG file), we defined high school dropouts as those with fewer than 12 years of completed schooling; high school graduates as those with either 12 completed years of schooling and/or a high school diploma or G.E.D.; some college as those attending some college or holding an Associate's Degree (either occupational/vocational or academic); and college graduates as those with a B.A. or higher.[3] Unlike all other Census and CPS samples used, the 1940 Census does not report whether years of schooling have been completed. Hence, for this sample, we included all of those with 12 years of reported education as high school graduates, and did not classify those with an uncompleted 13^{th} year as Some College.[4]

Because the correspondence between the old and new coding schemes is imperfect, we did not

[3] These categories correspond to the following CPS codes: Less than High School, 00 - 37; High School, 38 or 39; Some College, 40 - 42; and College Plus, 43 - 46. In the 1990 Census PUMS and the February 1990 CPS, these categories are: Less than High School, 0 - 8; High School, 9 or 10; Some College, 11 - 13; and College Plus, 14 - 17.

[4] For CPS samples found in Tables 4, 5, and 6, we used the conventional definitions of each educational category. For the old education term, these correspond to <12, 12, 13-15, and 16+ years of completed schooling for the four educational categories. For the new education term, the four categories are: less than high school diploma, high school diploma or G.E.D., some college or associate's degree, and B.A. or higher.

use the 1990 Census for any of our 1980 - 1990 workforce share, FTE share, or wage bill share change calculations, relying instead on the CPS MORG samples of the same years (which contain the old education question). For 1990 - 1995 changes, we faced a similar dilemma. While 1995 CPS data is coded with the same (new) education question found in the 1990 Census, the earnings concept (weekly vs. annual) and the nature of the questionnaire differ markedly between the two surveys. To avoid unreliable inferences stemming from using these surveys together, we instead used the February 1990 CPS — which contains both the old and new education question — and the 1995 CPS MORG file for calculating 1990 - 1995 changes. This approach also has limitations. First, because the February 1990 CPS asked both the old education and new education questions (the old question was asked first), it is unclear how answers to the new question were affected by answers to the old.[5] Second, as a monthly survey, the sample size for the Feb 1990 CPS is considerably smaller than the annual MORG file (particularly for earnings estimates where the sample is only 1/12th as large), implying that industry level observations from the February 1990 CPS are less reliable than in other samples. Finally, substantial revisions to the format and structure of the CPS in 1994 (including a new computer-based questionnaire) raise questions about the direct comparability of earnings and other data among CPS files before and after 1994. Hence, we emphasize that all tabulations and analyses using 1990 - 1995 changes should be treated with some caution.

In estimating the individual-level log wage equations presented in Table 5 that include years of schooling as a covariate, we used figures from Park's (1994) analysis of the February 1990 CPS to assign years of completed education to each worker in the October 1993 CPS based upon their race, gender and highest degree held. Years of potential experience were calculated as age minus imputed years of education minus 6. Aside from the obvious drawbacks posed by this imputation procedure (e.g., the mean years of education for a given degree may not have been stable since February 1990), it also creates a problem for OLS inasmuch as the variance of the imputed years of education variable is lower than the observed variance of the old educational term. Park (1994) reports that the imputation procedure leads to an approximately 1 log point increase in the estimated education coefficient in a standard OLS wage equation as compared to the same equation estimated with the old education variable.

Consistent industry and occupation codes

Although a majority of the Census Industries Codes (CICs) have remained unchanged since 1960 (aside from renumbering), a substantial number of new industries categories have emerged in later revisions which were formerly part of larger aggregates, while a smaller number of more detailed categories have been collapsed into aggregate categories. During a major revision to the CIC in the 1980 Census, a considerable number of industries were intertwined such that one or more old codes concorded with more than one new code. Our strategy in creating a consistent set of codes spanning the 1960, 1970, 1980 and 1990 CIC standard was to preserve industries that were present in all years, while re-combining industries that were disaggregated in later years or that became intertwined during recodings. Although in most cases it was clear whether industries should be retained intact or required merging, there were also a of number

[5] Frazis, Ports, and Stewart (1995) present evidence that answers to the new question were contaminated by answers to the old.

judgment calls. In these cases, we tried to strike a balance between maintaining consistency and preserving detail. The resulting set of codes contains 142 distinct industries for the 1960 - 1990 period, as compared to 149 industries in 1960, 213 in 1970, 231 in 1980, and 236 in 1990. These consistent 1960 - 1990 industries are listed in Appendix Table 2. We also created a set of consistent industry codes spanning the 1970 to 1990 period which are used in the models in Table 6. Because the 1960 codes impose the heaviest cost in lost detail compared to other periods, the 1970 - 1990 codes (which do not incorporate 1960 CICs) contain 52 additional distinct industries (a total of 194). Many of the reported estimates were performed at several levels of CIC detail to check their sensitivity to aggregation (i.e., with 60-90, 70-90, and 80-90 codes). In general, aggregation has little effect on the estimated coefficients. Crosswalks between the 142 consistent CICs and the 1960, 1970, 1980 and 1990 CIC standards are available from the authors upon request.

Data from the National Income and Product Accounts

We used data from the National Income and Product Accounts (NIPA) to measure capital intensity and high tech capital holdings and investment at the industry level between 1960 - 1990. The measures used from NIPA were industry gross capital stock and investment (equipment, structures, and total), and detailed industry capital stock and investment in the categories of Office Computing and Machinery (OCAM), Scientific and Engineering Equipment, Telecommunications equipment, and Photocopy and Related Equipment. We also used NIPA data to calculate FTEs by industry in 1960, 1970, 1980, and 1990. These FTEs were used as the denominator in our capital/FTE and equipment/FTE variables. To reduce measurement error, all variables in the NIPA (aside from FTEs) were constructed as 5-year centered averages of the respective data category.

To match data in the CPS and Census to data in the NIPA, we created a cross-walk between the NIPA categories (based on the SIC) and our 142 consistent CIC categories. The resulting aggregation of NIPA and CIC data yielded 47 consistent industries covering all industrial sectors excluding Government and Private Households, spanning the 1960 - 1990 CIC and the 1972 and 1987 Standard Industrial Classification (SIC). This crosswalk is available upon request.

Data on industry output

To construct the Real Industry Output variable, we used the BLS Industry Employment and Output Series which contains estimates of domestic industry output for 183 sectors in constant dollars from 1958 through the present. We matched the 183 BLS sectors to the 47 consistent NIPA sectors and, as above, used five year centered averages to calculate the value of output by sector. The crosswalk between BLS and NIPA sectors is available from the authors.

4-Digit SIC manufacturing data

For some of our analyses in the manufacturing sector, we used the NBER Manufacturing Productivity Database created by Eric Bartelsman and Wayne Gray. Documentation on this database is available in Bartelsman and Gray (1996) and at http:\\www.nber.org. Gordon Hanson and Robert Feenstra also graciously provided us with the outsourcing data used and described in Feenstra and Hanson (1996). Robert Feenstra provided us with import and export data from

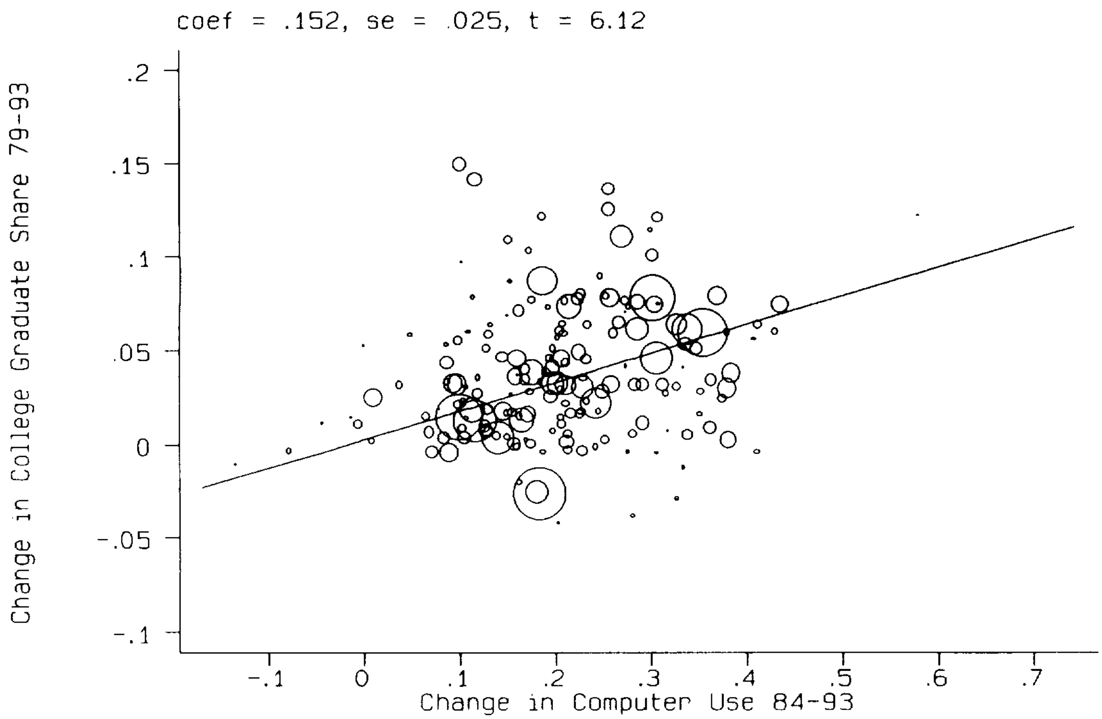
1958 to 1992 at the 4-digit SIC level. The import data is described in Feenstra (1996). Annual Survey of Manufacturers (ASM) data on computer investment at the 4-digit SIC level for 1977, 1982, and 1987 was provided by Eli Berman. See Berman, Bound and Griliches (1994) for details. The authors also thank Ken Troske for providing ASM computer investment data at the 3-digit level for the years 1977, 1982, 1987, and 1992.

Research and Development Expenditures Data

As a measure of industry R&D intensity, we used data from the National Science Foundation's (NSF) *Research and Development in Industry* series on company and other (except Federal) R&D funds as a percentage of net sales in R&D-performing manufacturing companies. To employ this data in conjunction with NIPA and Real Output data, we created an aggregate NIPA-NSF crosswalk which divides the manufacturing sector into 15 consistent industries for the 1960 -1995 period. This crosswalk is available upon request. To reduce measurement error and replace missing observations stemming from censored observations and incomplete data in the NSF file, we used multi-year means to calculate some observations. In particular, 1960 R&D levels are 1958, 1963 industry means; 1970 R&D levels are 1967, 1971, and 1972 industry means; 1980 levels are taken from 1981 data (because of missing observations in 1980); and, for the sake of consistency with the 1980 data, 1990 levels are taken from 1991 data. Details on further imputations are available from the authors on request. Because R&D levels are quite stable over multi-year periods, we feel confident that these steps do not substantially reduce the veracity of the R&D data or the resultant estimates. We thank Nachum Sicherman for generous assistance with the NSF data.

Figure 1: Changes in Computer Use and Industry Work-Force Educational Shares

(a) College Graduates



(b) High School Graduates

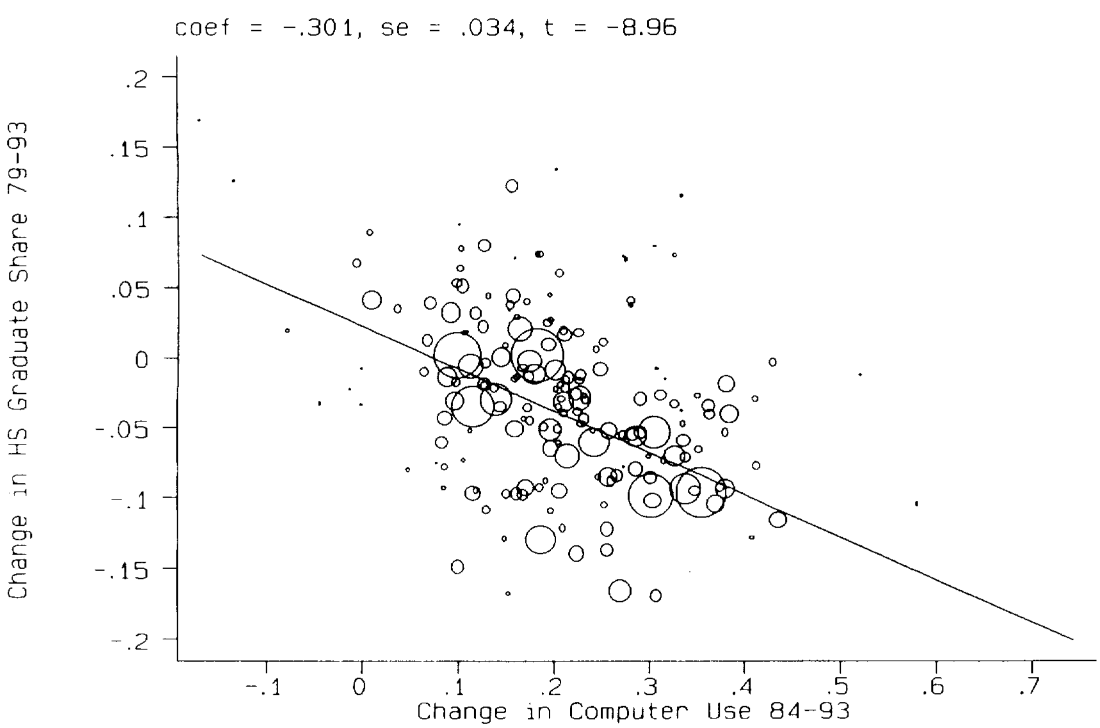


Table 1: Levels and Changes in the Educational Composition of Employment and the College/High School Wage Premium, 1940-1995.

A. Full-Time Equivalent Employment Shares by Education Level (in percent) and Log College/High School Wage Premium

	High School Dropouts	High School Graduates	Some College	College Graduates	College Equivalents	Log College/ HS Wage
1940 Census	67.9	19.5	6.5	6.1	9.4	.487
1950 Census	58.6	24.4	9.2	7.8	12.4	.313
1960 Census	49.5	27.7	12.2	10.6	16.7	.395
1970 Census	35.9	34.7	15.6	13.8	21.6	.438
1980 Census	20.7	36.1	22.8	20.4	31.8	.343
1980 CPS	19.1	38.0	22.0	20.9	31.9	.320
1990 CPS	12.7	36.2	25.1	26.1	38.6	.453
1990 Census	11.4	33.0	30.2	25.4	40.6	.471
Feb. 90 CPS	11.5	36.8	25.2	26.5	39.1	.471
1995 CPS	9.0	33.7	29.4	27.9	42.6	.481

B. Changes in College/Non-College Log Relative Wages and Employment (100 * Annual Log Changes)

	Wages	College Graduate FTEs	College Equivalent FTEs
1940 - 1950	-1.74	2.54	3.12
1950 - 1960	0.82	3.43	3.51
1960 - 1970	0.42	3.00	3.19
1970 - 1980	-0.94	4.69	5.26
1980 - 1990 (CPS-CPS)	1.33	2.88	2.94
1990 - 1995 (Cen-CPS)	0.19	2.53	1.68
1990 - 1995 (CPS-CPS)	0.19	1.47	2.94

Table 1 Notes:

Full-Time Equivalent (FTE) shares are calculated for samples which include all workers ages 18 - 65 in paid employment (both wage and salary and self-employed workers) during the survey reference week for each Census and CPS sample. Usual weekly hours for CPS samples are imputed for the self-employed using average usual weekly hours for wage and salary workers in the same industry-education-year cell. FTE shares are defined as the share of total weekly hours supplied by each education group. Samples are drawn from the 1940, 1950, 1960, 1970, 1980, and 1990 Census PUMS; the 1980, 1990, and 1995 Merged Outgoing Rotation Groups (MORG) of the Current Population Survey; and the February 1990 Current Population Survey. College equivalents are defined as those with a college education plus half of those with some college. Non-college (or high school) equivalents are those with 12 or fewer years of schooling (or high school diploma or less) plus half of those with some college.

The log college/high school wage differentials are the estimated college (exactly 16 years of schooling or a B.A. degree) wage premium relative to high school workers (those with exactly 12 years of education or a high school diploma) in the indicated years. The differentials are estimated with cross-section log hourly earnings regressions for wage and salary workers in each sample with dummies for single years of schooling, a quartic in experience, three region dummies, a part-time dummy, a female dummy, a nonwhite dummy, interaction terms between the female dummy and the quartic in experience and the nonwhite dummy. In CPS samples, hourly earnings are calculated as the ratio of usual weekly earnings to usual weekly hours, and, in Census samples, as annual earnings divided by the product of weeks worked in the previous year and hours worked in the survey week. The February 1990 and 1995 college/high school premiums are estimated for full-time workers only. Annualized log wage changes for the 1990-95 period reported in the first column of Panel B are based on the college/high school differentials estimated from the February 90 CPS and 1995 CPS MORG samples. See the data appendix for details.

Table 2: College and College Equivalent Wage-Bill Shares, Supply and Demand Shifts, 1940-1995.

A. Changes in College/Non-College Log Relative Wages, Wage Bill, and Supply (100 * Annual Log Changes)

		College Graduates		College Equivalents	
	Relative Wage	Relative Wage Bill	Relative Supply Change	Relative Wage Bill	Relative Supply Change
1940 - 1950	-1.74	-0.13	1.61	0.72	2.46
1950 - 1960	0.82	3.76	2.94	3.75	2.92
1960 - 1970	0.42	3.35	2.92	3.25	2.83
1970 - 1980	-0.94	3.56	4.50	4.25	5.19
1980 - 1990	1.33	3.99	2.66	4.05	2.71
1990 - 1995 (Cen-CPS)	0.19	2.28	2.09	1.70	1.51
1990 - 1995 (CPS-CPS)	0.19	1.78	1.59	2.69	2.50

B. Implied Relative Demand Shifts Favoring College Graduates (100 * Annual Log Changes)

	$\sigma = 1.4$	$\sigma = .5$	$\sigma = 1$	$\sigma = 1.5$	$\sigma = 2$
1940 - 1950	-0.82	0.74	-0.13	-1.00	-1.87
1950 - 1960	4.09	3.35	3.76	4.17	4.59
1960 - 1970	3.52	3.14	3.35	3.56	3.77
1970 - 1980	3.18	4.03	3.56	3.09	2.61
1980 - 1990	4.53	3.33	3.99	4.66	5.33
1990 - 1995 (Cen-CPS)	2.36	2.19	2.28	2.37	2.47
1990 - 1995 (CPS-CPS)	1.85	1.69	1.78	1.87	1.97

C. Implied Relative Demand Shifts Favoring College Equivalents (100 * Annual Log Changes)

	$\sigma = 1.4$	$\sigma = .5$	$\sigma = 1$	$\sigma = 1.5$	$\sigma = 2$
1940 - 1950	0.02	1.59	0.72	-0.15	-1.02
1950 - 1960	4.08	3.34	3.75	4.16	4.57
1960 - 1970	3.42	3.04	3.25	3.46	3.67
1970 - 1980	3.87	4.72	4.25	3.77	3.30
1980 - 1990	4.58	3.38	4.05	4.71	5.38
1990 - 1995 (Cen-CPS)	1.77	1.60	1.70	1.79	1.88
1990 - 1995 (CPS-CPS)	2.76	2.60	2.69	2.78	2.88

Table 2 Notes:

σ is the aggregate elasticity of substitution between college and non-college workers in Panel B, and between college equivalent and non-college equivalent workers in Panel C.

Wage-bill shares, defined as the share of total weekly wages paid to each education group, are calculated from the samples described in the notes to Table 1. College equivalents are defined as those with a college education plus half of those with some college. Non-college (or high school) equivalents are those with 12 or fewer years of schooling (or high school diploma or less) plus half of those with some college. In CPS samples, hourly wages for the self-employed are imputed using average weekly wages for wage and salary workers in the same industry-education-year cell. Annual log wage changes for the 1990-95 period reported in the first column of Panel A are based on the college/high school differentials estimated from the February 1990 CPS and 1995 CPS MORG samples. The relative supply changes tabulated in the third and fifth columns of Panel A are the difference between the change in the relative wage bill (column 1) and the change in relative college/high school wages (columns 2 and 4 for college and college-equivalents respectively). See the data appendix for details.

Table 3: **Between- and Within- Industry Decomposition of the Increase in the Share of College Graduates in Employment, 1960 - 1995.** ***(100 * Annual Change in College Graduate Employment and Wage-Bill Share)***

A. Employment

	All Industries			*Manufacturing*			*Non-Manufacturing*		
	Between	**Within**	**Total**	**Between**	**Within**	**Total**	**Between**	**Within**	**Total**
1960 - 70 Census-Cens	.237	.087	.324	.044	.121	.166	.287	.074	.361
1970 - 80 Census-Cens	.122	.464	.586	.024	.375	.399	.115	.494	.609
1980 - 90 CPS-CPS	.098	.371	.469	.064	.441	.505	.055	.353	.408
1990 - 95 CPS-Census	-.054	.497	.444	-.120	.618	.498	-.064	.472	.408
1990 - 95 CPS-CPS	.043	.206	.249	-.139	.266	.127	.049	.194	.242

B. Wage Bill

	All Industries			*Manufacturing*			*Non-Manufacturing*		
	Between	**Within**	**Total**	**Between**	**Within**	**Total**	**Between**	**Within**	**Total**
1960 - 70 Census-Cens	.278	.232	.511	.068	.273	.342	.320	.214	.534
1970 - 80 Census-Cens	.107	.555	.662	.026	.471	.497	.094	.586	.680
1980 - 90 CPS-CPS	.266	.612	.878	.163	.745	.908	.224	.573	.797
1990 - 95 CPS-Census	.153	.384	.537	-.039	.865	.826	.221	.260	.480
1990 - 95 CPS-CPS	.210	.225	.435	-.155	.456	.301	.308	.164	.472

Notes. 1960-70 and 1970-80 changes use data from the 1960, 1970 and 1980 Census PUMS. 1980-1990 changes use data from the CPS Merged Outgoing Rotation Group files. 1990-95 CPS-Census changes use the 1990 Census PUMS and the 1995 CPS Merged Outgoing Rotation Groups. 1990-95 CPS-CPS changes use the Feb. 1990 CPS and the 1995 CPS Merged Outgoing Rotation Groups. Decompositions are based on the 140 consistent CICs described in the data appendix (59 in manufacturing, 81 in non-manufacturing). Employment and wage-bill shares are based on all currently employed wage & salary and self-employed workers in the Census and CPS at the survey dates. Hourly wages are imputed for the self-employed in each sample using the average hourly wage for wage & salary workers in the same industry-education cell. Hours are imputed for the self-employed in the CPS in the same manner, using average hours and wages of salary workers in the same industry-education cells.

Table 4: **Percent of Workers in Various Categories Who Directly Use a Computer at Work.**

	October 1984	October 1989	October 1993
Use a computer			
All Workers	25.1	37.4	46.6
Gender			
Male	21.6	32.2	41.1
Female	29.6	43.8	53.2
Education			
Less than HS	5.1	7.7	10.4
High School	19.2	28.4	34.6
Some College	30.6	45.0	53.1
College +	42.1	58.5	70.2
Race			
White	25.8	38.5	48.0
Black	18.6	28.1	36.7
Age			
Age 18 - 24	20.5	29.6	34.3
Age 25 - 39	29.6	41.4	49.8
Age 40 - 54	23.9	38.9	50.0
Age 55 - 64	17.7	27.0	37.3
Occupation			
Blue collar	7.1	11.2	17.1
White collar	39.7	56.6	67.6
Union Member			
Yes	19.9	31.8	39.1
No	25.3	37.7	46.9
Hours			
Part-time	14.8	24.4	29.3
Full-time	29.3	42.3	51.0
Region			
Northeast	25.5	37.6	46.9
Midwest	24.3	36.6	46.7
South	23.2	36.6	45.0
West	28.9	39.7	48.8

Data source: October 1984, 1989, and 1993 Current Population Surveys. Sample sizes are 61,704, 62,748 and 59,852 in 1984, 1989 and 1993 respectively. Results are weighted by CPS sample weights. Sample includes workers ages 18 - 64 who were working, or with job but not at work in previous week.

Table 5: OLS Cross-Section Estimates of the Relationship Between Computer Use and Wages. *(Dependent variable: Log Hourly Wages)*

	1984					1989					1993				
	(1)	(2)	(3)	(4)	(5)	(1)	(2)	(3)	(4)	(5)	(1)	(2)	(3)	(4)	(5)
Uses Computer at work		.170 (0.008)	.074 (0.048)		.173 (0.014)		.188 (0.008)	.005 (0.043)		.176 (0.013)		.023 (0.008)	-.214 (0.045)		.185 (0.013)
Years of Education	.076 (0.001)	.069 (0.001)	.067 (0.002)			.086 (0.001)	.075 (0.002)	.071 (0.002)			.093 (0.002)	.080 (0.002)	.067 (0.002)		
Less than HS				-.183 (0.012)	-.166 (0.012)				-.204 (0.012)	-.176 (0.013)				-.201 (0.013)	-.163 (0.014)
Some College				.141 (0.010)	.121 (0.011)				.176 (0.010)	.134 (0.012)				.153 (0.009)	.112 (0.012)
College plus				.410 (0.009)	.380 (0.012)				.473 (0.010)	.418 (0.014)				.505 (0.010)	.399 (0.016)
Computer use * Education			0.0069 (0.0034)					.013 (0.003)					.031 (0.003)		
Computer use * Less than HS					.037 (0.042)					.068 (0.040)					.030 (0.040)
Computer use * Some College					.001 (0.021)					.023 (0.019)					.012 (0.018)
Computer use * College Plus					-.018 (0.020)					.006 (0.020)					.054 (0.021)
Experience	.027 (0.001)	.027 (0.001)	.027 (0.001)	.028 (0.001)	.028 (0.001)	.027 (0.001)	.027 (0.001)	.027 (0.001)	.029 (0.001)	.028 (0.001)	.027 (0.001)	.026 (0.001)	.027 (0.001)	.030 (0.001)	.029 (0.001)
Exp^2 * 100	-.042 (0.002)	-.041 (0.002)	-.042 (0.002)	-.048 (0.002)	-.047 (0.002)	-.044 (0.002)	-.041 (0.002)	-.042 (0.002)	-.050 (0.002)	-.047 (0.002)	-.043 (0.003)	-.041 (0.003)	-.042 (0.003)	-.051 (0.003)	-.048 (0.003)
Part Time	-.287 (0.010)	-.257 (0.010)	-.257 (0.010)	-.280 (0.010)	-.249 (0.010)	-.261 (0.011)	-.221 (0.010)	-.221 (0.010)	-.250 (0.011)	-.211 (0.010)	-.222 (0.011)	-.177 (0.010)	-.176 (0.010)	-.218 (0.011)	-.172 (0.010)
R-squared	.429	.446	.446	.424	.442	.427	.451	.452	.426	.449	.396	.424	.428	.396	.424
Standard Error	.410	.404	.404	.412	.406	.420	.411	.411	.421	.412	.425	.415	.414	.425	.415
n	13,335	13,335	13,335	13,335	13,335	13,379	13,379	13,379	13,379	13,379	13,305	13,305	13,305	13,305	13,305

Notes. Standard errors are in parentheses. Data sources October 1984, 1989, and 1993 CPS. All models also include controls for experience and its square, black, other race, SMSA status, veteran status, female, married, female * married interaction, union membership, 3 region dummies, and an intercept.

Table 6: OLS First-Difference Panel Estimates of the Relationship Between Computerization and Educational Upgrading in 3-Digit Industries Between 1979 and 1993. ***(Dependent Variable: 100 * Annual Change in Employment Share)***

Panel A:		**Males & Females**				**Males & Females**		
	College	**Some College**	**HS Grad**	**Less than HS**	**College**	**Some College**	**HS Grad**	**Less than HS**
Δ Computer Use 1984-93	.152	.016	-.301	.133	.190	.060	-.251	.001
	(0.025)	(0.020)	(0.034)	(0.026)	(0.029)	(0.024)	(0.040)	(0.025)
Mean Ed '74					-.005	-.006	-.006	.017
					(0.002)	(0.002)	(0.003)	(0.002)
Intercept	.028	.612	.223	-.863	.549	1.228	.911	-2.687
	(0.059)	(0.048)	(0.079)	(0.060)	(0.229)	(0.185)	(0.309)	(0.194)
R-Squared	.166	.003	.299	.126	.190	.063	.319	.420
n	191	191	191	191	190	190	190	190
Weighted mean Change	.357	.646	-.427	-.576	.357	.646	-.427	-.576
Panel B:		**Males**				**Males**		
	College	**Some College**	**HS Grad**	**Less than HS**	**College**	**Some College**	**HS Grad**	**Less than HS**
Δ Computer Use 1984-93	.118	.013	-.212	.082	.156	.081	-.178	-.058
	(0.027)	(0.024)	(0.033)	(0.028)	(0.033)	(0.028)	(0.041)	(0.030)
Mean Ed '74					-.004	-.008	-.004	.016
					(0.002)	(0.002)	(0.003)	(0.002)
Intercept	.042	.516	.243	-.801	.513	1.350	.663	-2.527
	(0.061)	(0.054)	(0.075)	(0.062)	(0.246)	(0.211)	(0.306)	(0.220)
R-Squared	.093	.002	.180	.045	.112	.084	.189	.293
n	190	190	190	190	189	189	189	189
Weighted mean Change	.280	.542	-.186	-.636	.280	.542	-.186	-.636
Panel C:		**Females**				**Females**		
	College	**Some College**	**HS Grad**	**Less than HS**	**College**	**Some College**	**HS Grad**	**Less than HS**
Δ Computer Use 1984-93	.137	-.014	-.258	.135	.159	.011	-.232	.061
	(0.027)	(0.022)	(0.039)	(0.024)	(0.028)	(0.023)	(0.041)	(0.020)
Mean Ed '74					-.005	-.006	-.006	.018
					(0.002)	(0.002)	(0.003)	(0.002)
Intercept	.154	.781	-.141	-.794	.756	1.489	.569	-2.814
	(0.068)	(0.056)	(0.099)	(0.060)	(0.278)	(0.226)	(0.408)	(0.196)
R-Squared	.125	.002	.190	.149	.149	.056	.205	.472
n	189	189	189	189	187	187	187	187
Weighted mean Change	.470	.748	-.734	-.484	.470	.748	-.734	-.484

Notes: Standard errors are in parentheses. Δ Computer use is 10 times the change in industry computer use frequency between 1984 and 1993 as reported in the October 1984 and 1993 CPS. Change in educational shares are measured as 100 times the annual change in the share of industry workers in each educational category as reported in the 1979 and 1993 Annual Earnings Files of the Current Population Survey. Lagged industry education means are drawn from the May 1974 CPS and are multiplied by 10. Industries are coded as 191 consistent CICs, spanning the 1970, 1980, and 1990 CIC standard. All regressions are weighted by the product over the sum of the industry's share of total employment in each of the two years used in constructing the dependent variable. See the data appendix for details.

<u>Table 7:</u> OLS First-Difference Estimates of the Relationship Between Computerization 1984 - 1993 and Growth in the College Wagebill Share in 3-Digit Industries 1960 - 1995. (*Dependent variable: 100 * Annual Change in College Wage-Bill Share*)

	Census - Census 1960 - 1970			Census - Census 1970 - 1980			CPS - CPS 1980 - 1990			CPS Feb. 90 - CPS 95 1990 - 1995		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Δ Computer Use 1984-93	.071 (0.025)	.097 (0.031)	.037 (0.027)	.127 (0.031)	.200 (0.036)	.132 (0.033)	.147 (0.046)	.204 (0.056)	.096 (0.047)	.204 (0.109)	.301 (0.130)	.112 (0.122)
Mean Ed '60		-.003 (0.002)	-.008 (0.002)		-.007 (0.002)	-.012 (0.002)		-.005 (0.003)	-.012 (0.003)		-.009 (0.007)	-.020 (0.007)
Computer Use '84			.117 (0.016)			.120 (0.018)			.194 (0.024)			.336 (0.059)
Intercept	.085 (0.058)	.319 (0.167)	.706 (0.150)	.279 (0.073)	.910 (0.191)	1.247 (0.173)	.287 (0.108)	.757 (0.289)	1.259 (0.244)	-.241 (0.266)	.604 (0.682)	1.311 (0.628)
R-Squared	.053	.068	.342	.107	.182	.388	.070	.091	.394	.025	.038	.221
n	140	140	140	140	140	140	140	140	140	140	140	140
Weighted Mean Change	.233	.233	.233	.554	.554	.554	.614	.614	.614	.228	.228	.228

Notes: Standard errors are in parentheses. Computer use is measured as 10 times the change in industry computer use frequency between 1984 and 1993 as reported in the October 1984 and 1993 CPS. College wagebill shares are measured as the industry wage-bill share of workers with 16+ completed years of schooling and as the industry wage-bill share of workers holding at least a B.A. in 1990 - 1995 changes. Levels variables (mean education and computer use frequency in 1984) are multiplied by 10. 1960-1970 and 1970-1980 changes use data from the 1960, 1970, and 1980 Census PUMS. 1980 to 1990 changes use data from the 1980 and 1990 CPS Merged Outgoing Rotation Group files. 1990-1995 CPS-CPS changes use data from the February 1990 CPS and the 1995 CPS Merged Outgoing Rotation Groups. Industries are coded as 140 consistent CICs, spanning the 1960, 1970, 1980, and 1990 CIC standard. All regressions are weighted by the product over the sum of the industry share of the total wage bill in each of the two years used in constructing the dependent variable. See the data appendix for details.

Table 8: Computers, Capital Intensity, and Skill Upgrading, 1960 - 1990 in Non-agricultural, Predominantly Private Sector Industries. ***Dependent Variable: 100 * Annual Change in the College Graduate Wage-Bill Share***

						Manu-Facturing	Non-Manu-Facturing
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
$Log(C/L)_{-1}$		.157	.134	.130	.137	.154	.167
		(0.020)	(0.024)	(0.021)	(0.026)	(0.019)	(0.031)
Δ Log(C/L)					.005		
					(0.004)		
Δ Log (K/L)			.024		.021	.133	.003
			(0.014)		(0.014)	(0.017)	(0.011)
Δ Log (K/Y)				.014			
				(0.010)			
Δ Log Y				.037			
				(0.016)			
1970-80 Dummy	.297	.313	.337	.363	.260	.184	.419
	(0.040)	(0.042)	(0.042)	(0.046)	(0.088)	(0.075)	(0.041)
1980-90 Dummy	.482	.279	.346	.384	.240	.384	.276
	(0.071)	(0.064)	(0.082)	(0.096)	(0.129)	(0.094)	(0.095)
Intercept	.258	.739	.586	.487	.613	.305	.733
	(0.036)	(0.072)	(0.112)	(0.118)	(0.121)	(0.111)	(0.136)
R-Squared	.309	.522	.543	.547	.549	.696	.647
Standard error	.301	.251	.247	.247	.246	.215	.218
n	123	123	123	123	123	60	63

Notes. The numbers in parentheses are Huber-White robust standard errors that allow for grouped errors by industry. Each column represents a pooled regression of decadal changes in the college graduate wage-bill share for 1960-70, 1970-80, and 1980-90. Columns (1) - (5) include 41 NIPA non-agricultural, predominantly private-sector industries. Column (6) includes 20 manufacturing industries. Column (7) includes 21 non-manufacturing industries. Changes in the college graduate wage-bill share were calculated from the Census PUMS for 1960-70 and 1970-80 and from the CPS Merged Outgoing Rotation Group files for 1980-90. C/L and K/L were calculated from NIPA data. Y was calculated from the BLS Domestic Industry Output data. All regressions are weighted by the product over the sum of the industry share of the total wage bill in each of the two years used in constructing the dependent variable. See the data appendix for details.

C/L = real net stock of office, computing, and accounting machinery capital per FTEE
K/L = real net capital stock per FTEE
Y = real output
Δ indicates 100 times the annual change in the variable.

Table 9: R&D, Computer Use, Computer Investment, and Skill Upgrading in the Manufacturing Sector, 1960 - 1990. *Dependent Variable: 100 * Annual Change in the College Graduate Wage-Bill Share*

	(1)	(2)	(3)	(4)	(5)	(6)
Log(C/L)$_{-1}$	.146	.082		-.010		
	(0.020)	(0.040)		(0.042)		
R&D$_{-1}$		7.678			3.669	
		(2.069)			(2.047)	
R&D$_{-1}$ * 1960-70			3.817			-11.633
			(4.480)			(4.558)
R&D$_{-1}$ * 1970-80			5.419			6.070
			(1.819)			(2.642)
R&D$_{-1}$ * 1980-90			16.747			9.677
			(2.571)			(2.646)
Computer Use				1.029	.736	1.828
*** 1960-70**				(0.447)	(0.427)	(0.368)
Computer Use				.497	.134	-.078
*** 1970-80**				(0.237)	(0.199)	(0.201)
Computer Use				2.637	2.205	1.409
*** 1980-90**				(0.301)	(0.205)	(0.342)
Δ Log (K/L)	.145	.108	.071	.055	.052	.058
	(0.014)	(0.014)	(0.025)	(0.019)	(0.010)	(0.011)
1970-80 Dummy	.152	.116	.092	.276	.284	.315
	(0.078)	(0.072)	(0.066)	(0.102)	(0.103)	(0.087)
1980-90 Dummy	.385	.386	.177	.100	.092	.181
	(0.107)	(0.087)	(0.090)	(0.138)	(0.129)	(0.110)
Intercept	.250	.056	.008	-.174	-.119	-.165
	(0.129)	(0.143)	(0.103)	(0.207)	(0.116)	(0.099)
R-Squared	.755	.811	.841	.869	.875	.914
Standard error	.195	.173	.161	.148	.145	.124
n	42	42	42	42	42	42

Notes. The numbers in parentheses are Huber-White robust standard errors that allow for grouped errors by industry. Each column represents a pooled regression of decadal changes in the college graduate wage-bill share for 1960-70, 1970-80, and 1980-90 in 14 consistent manufacturing industries. Changes in the college graduate wage-bill share were calculated from the Census PUMS for 1960-70 and 1970-80 and from the CPS Merged Outgoing Rotation Group files for 1980-90. C/L and K/L were calculated from NIPA data. R&D was caculated from NSF data. All regressions are weighted by the product over the sum of the industry share of the total wage bill in each of the two years used in constructing the dependent variable. See the data appendix for details.

R&D = Industry R&D funds as a percentage of net sales
C/L = real net stock of office, computing, and accounting machinery capital per FTEE
K/L = real net capital stock per FTEE
Computer Use = Computer use frequency from October 1984 Current Population Survey
Δ indicates 100 times the annual change in the variable.

Weighted mean of dependent variable: .311 in 1960-70, .453 in 1970-80, and .838 in 1980-90.
Weighted mean of R&D: .0172 in 1960, .0212 in 1970, and .0271 in 1980.

Table 10: Change in the Nonproduction Worker Share of the Wage Bill in 450 Four-Digit Manufacturing Industries, 1959 - 1989. ***Dependent Variable: 100 * Annual Change in the Nonproduction Wage-Bill Share***

	Pooled Specifications						1959-69	1969-79	1979-89
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Δ Log (K/Y)				.027	.029	.025	.011	.039	.049
				(0.006)	(0.009)	(0.006)	(0.010)	(0.013)	(0.010)
Δ Log Y				.019	.017	.018	.024	.032	.017
				(0.006)	(0.006)	(0.006)	(0.011)	(0.014)	(0.008)
CI/I		2.862		2.658	2.477	2.497	2.200	3.241	2.192
		(0.620)		(0.679)	(0.693)	(0.685)	(0.679)	(1.175)	(0.865)
Δ Log TFP					.010				
					(0.015)				
Δ Sm					.019				
					(0.055)				
Δ Sx					.052	.058	.126	.033	.066
					(0.027)	(0.028)	(0.079)	(0.040)	(0.033)
Δ So			.147		.052	.059	.053	.048	.116
			(0.050)		(0.038)	(0.049)	(0.075)	(0.052)	(0.143)
1969-79 dummy	.017	.016	-.007	.038	.011	.012			
	(0.046)	(0.045)	(0.047)	(0.040)	(0.039)	(0.039)			
1979-89 dummy	.265	.175	.245	.224	.211	.215			
	(0.037)	(0.042)	(0.036)	(0.045)	(0.036)	(0.041)			
Constant	.110	.037	.084	-.051	-.062	-.057	-.076	-.096	.144
	(0.031)	(0.030)	(0.031)	(0.031)	(0.037)	(0.031)	(0.058)	(0.050)	(0.044)
R-Squared	.082	.180	.102	.205	.220	.218	.144	.159	.215
n	1350	1350	1350	1350	1350	1350	450	450	450
Standard error	.407	.385	.403	.379	.376	.376	.330	.387	.394
Wtd. Mean of Dep Var							.110	.126	.375

Notes. Standard errors are in parentheses. Huber-White robust standard errors are reported in all columns; the standard errors in columns (1)-(6) allow for grouped errors by four-digit industry. All regressions are weighted by the average industry share of the total manufacturing wage bill in the two years used in constructing the dependent variable. Δ indicates 100 times the annual change in the variable. Sources: Bartelsman and Gray (1996); Berman, Bound & Griliches (1994); Feenstra (1996); and Feenstra and Hanson (1996).

K/Y = Real capital stock to shipment ratio.
Y = Real value of shipments.
TFP = 5-factor total factor productivity.
Sm = Imports/(Imports+Shipments).
Sx = Exports/Shipments.
CI/I = Ratio of Computer Investment to Total Investment.
So = Outsourcing=(Imported Inputs)/(Total Non-Energy Material Purchases)

CI/I: For 1959-69 and 1969-79 changes, CI/I is defined as the 1977 computer investment share; for 1979-89 changes, CI/I is the average of the computer investment share in 1982 and 1987.
Δ So: For 1959-69 changes, Δ So is 100 times the minimum of 1/10th of the level of outsourcing in 1972 and the annual change in outsourcing from 1972-79; for 1969-79, it is 100 times the annual change in outsourcing from 1972-79; and for 1979-89, it is the 100 times the annual change in outsourcing from 1979-90.

Appendix Table A1: Employment and Wage-Bill Shares by Educational Category, 1940 - 1995.

A. Employment Shares (in percent): 1940 - 1995

	High School Dropouts	High School Graduates	Some College	College Graduates	College Equivalents
1940 Census	68.7	19.0	6.3	6.0	9.2
1950 Census	58.5	24.3	9.5	7.7	12.4
1960 Census	50.0	27.4	12.5	10.1	16.4
1970 Census	36.1	34.1	16.4	13.4	21.5
1980 Census	21.4	35.8	23.6	19.2	31.0
1980 CPS	19.3	38.0	22.8	19.9	31.3
1990 CPS	13.1	36.3	26.0	24.6	37.6
1990 Census	12.0	33.3	30.8	24.0	39.3
Feb. 90 CPS	12.0	37.0	26.1	24.9	38.0
1995 CPS	9.7	34.0	30.1	26.2	41.2

B. Wage-Bill Shares (in percent): 1940 - 1995

	High School Dropouts	High School Graduates	Some College	College Graduates	College Equivalents
1940 Census	58.4	20.8	8.8	12.0	16.4
1950 Census	52.1	25.0	11.0	11.9	17.4
1960 Census	42.4	27.1	14.1	16.4	23.4
1970 Census	29.7	32.3	16.5	21.5	29.7
1980 Census	17.0	32.5	22.4	28.1	39.3
1980 CPS	15.4	34.2	21.8	28.5	39.5
1990 CPS	8.6	29.9	24.2	37.3	49.4
1990 Census	8.0	26.8	28.5	36.7	51.0
Feb. 90 CPS	7.8	29.9	25.0	37.2	49.7
1995 CPS	5.6	27.6	27.4	39.4	53.1

Notes. Employment and wage-bill shares are calculated from the samples described in the notes to Table 1. College equivalents are defined as those with a college education plus half of those with some college. See the data appendix for details.

Appendix Table A2: College Employment Shares 1980 - 1990 (Initial Levels and Changes) and Computer Use 1984 - 1993 (Initial Levels and Changes) by Consistent 1960-1990 CIC.

Ind6090 Code	Title	Workers in 1990	College Share 90	80-90 Change in College Share	Computer Use in 84	84-93 Change in Computer Use
220	Leather tanning and finishing	10,065	0.092	0.031	0.207	-0.169
381	Watches, clocks, and clockwork operated devices	13,767	0.282	0.186	0.133	-0.133
230	Logging	153,377	0.044	0.004	0.086	-0.077
402	Taxicab service	107,827	0.165	0.080	0.086	-0.044
261	Pottery and related products	41,332	0.127	-0.063	0.105	-0.012
271	Iron and stell foundaries	129,843	0.073	0.005	0.209	-0.005
782	Shoe repair shops	9,808	0.105	0.091	0.000	0.000
241	Misc. wood products	145,870	0.075	0.011	0.074	0.009
761	Private households	816,719	0.051	0.014	0.007	0.011
41	Coal mining	161,231	0.090	0.033	0.089	0.037
650	Liquor stores	130,888	0.209	0.107	0.088	0.050
100	Meat products	446,057	0.056	0.009	0.074	0.069
786	Beauty shops; Barber shops	791,113	0.025	0.002	0.008	0.077
392	Not specified manufacturing industries	38,907	0.121	0.039	0.096	0.079
801	Bowling alleys, billiard and pool parlors	55,346	0.042	-0.038	0.131	0.086
401	Bus service and urban transit	443,180	0.110	0.055	0.071	0.087
151	Apparel and accessories, except knit	894,115	0.062	0.008	0.059	0.094
420	Water transportation	172,387	0.216	0.092	0.247	0.099
66	Construction	7,449,205	0.098	0.015	0.069	0.100
102	Canned and preserved fuits and vegetables	237,639	0.093	0.004	0.170	0.100
31	Fishing, hunting and trapping	75,901	0.078	-0.047	0.133	0.102
16	Ag production crops & livestock; Ag services, except horticultural; Horticultural services	2,727,738	0.117	0.017	0.044	0.103
152	Misc. fabricated textile products	144,496	0.089	0.013	0.086	0.103
766	Services to dwellings and other buildings; Misc. repair services; Electrical repair shops	1,373,433	0.074	0.011	0.063	0.103
132	Knitting mills	110,363	0.064	-0.011	0.072	0.104
391	Misc. manufacturing industries and toys, amusement and sporting goods	507,131	0.123	-0.003	0.189	0.104
40	Metal mining	66,696	0.175	0.012	0.353	0.108
112	Sugar and confectionary products	107,347	0.104	0.025	0.221	0.113
790	Dressmaking shops	34,319	0.137	0.067	0.000	0.115
641	Eating and drinking places	4,946,621	0.087	0.009	0.072	0.115
771	Laundry, cleaning, and garment services	477,421	0.059	0.007	0.026	0.118
111	Bakery products	226,509	0.074	0.010	0.079	0.127
231	Sawmills, planning mills, and millwork	408,870	0.065	0.002	0.077	0.128
270	Blast furnaces, steelworks, rolling and finishing mills	386,962	0.115	0.019	0.233	0.129
621	Gasoline service stations	455,334	0.080	0.026	0.155	0.129
636	Grocery Stores; Retail Bakeries; Food stores, n.e.c.	2,888,774	0.073	0.012	0.114	0.140

166	Screw machine products; metal forgings and stampings; and Misc. fabricated metal products	551,334	0.096	0.024	0.177	0.141
756	Automotive repair shops; automotive services, except repair	1,353,520	0.053	0.002	0.090	0.145
660	Jewelry stores	189,748	0.193	0.032	0.125	0.148
776	Hotels and motels; Loding places, except hotels and motels	1,663,369	0.114	0.015	0.155	0.148
201	Misc. petroleum and coal products	29,046	0.174	0.038	0.095	0.150
186	Electronic computing equipment; Office and accounting machines	735,818	0.455	0.185	0.731	0.151
30	Forestry	74,392	0.255	-0.088	0.371	0.153
251	Cement, concrete, and gypsum, and plaster products	200,093	0.104	0.027	0.143	0.155
142	Yarn, thread, and fabric mills	424,004	0.069	0.003	0.117	0.156
242	Furniture and fixtures	672,415	0.067	0.017	0.094	0.158
411	Warehousing and storage	139,038	0.099	0.024	0.164	0.159
222	Leather products, except footwear	39,356	0.049	-0.014	0.199	0.160
802	Misc. entertainment and recreation services	800,327	0.193	0.033	0.113	0.160
171	Newspaper publishing and printing	500,153	0.276	0.058	0.382	0.162
262	Misc. nonmetallic mineral and stone products	144,955	0.150	0.023	0.164	0.163
410	Trucking service	1,819,808	0.086	0.030	0.106	0.165
360	Ship and boat building and repairing	251,872	0.118	0.039	0.149	0.168
236	Railroad locomotives and equipment; Cycles and Misc transporation equipment; Wood buildings and mobile homes	162,631	0.114	0.045	0.137	0.169
211	Other rubber products, and plastics footwear and belting + Tires & Inner tubes	210,991	0.109	-0.014	0.278	0.169
412	U.S. Postal Service	857,204	0.130	0.039	0.131	0.171
221	Footwear, except rubber and plastic	85,613	0.082	0.057	0.080	0.173
351	Transporation equipment	1,118,348	0.140	0.027	0.223	0.175
146	Primary aluminum industries; Other primary metal industries	343,257	0.124	0.011	0.198	0.186
181	Drugs	262,723	0.500	0.125	0.472	0.186
281	Cutlery, handtools, and other hardware	115,785	0.153	0.068	0.119	0.188
200	Petroleum refining	135,780	0.326	0.087	0.513	0.191
566	Lumber and construction materials; Metals and minerals, excpet petroleum; Scrap and waste materials; Paper and paper products; Alcoholic beverages; (all wholesale)	2,224,393	0.259	0.050	0.337	0.191
706	Banking; Credit agencies, n.e.c.; Savings and Loan associations	2,710,710	0.291	0.102	0.718	0.193
282	Fabricated structural metal products	488,990	0.093	-0.007	0.153	0.195
176	Engine and turbines; Construction and material handling machines; metalworking machinery; machinery, except electrical, n.e.c.; Not specified machinery	1,597,531	0.129	0.017	0.294	0.195
672	Fuel and ice dealers	116,430	0.104	0.031	0.122	0.196
421	Air transportation	727,153	0.290	0.087	0.490	0.198
50	Nonmetallic mining and quarrying, except fuel	113,497	0.058	-0.011	0.108	0.198
110	Gain mill products	142,878	0.159	0.010	0.318	0.203
150	Misc. textile mill products	40,317	0.071	-0.019	0.108	0.204
552	Petroleum products wholesale	161,137	0.280	0.097	0.274	0.204
681	Retail florists	193,747	0.147	0.028	0.142	0.206
250	Glass and glass products	193,125	0.165	0.076	0.161	0.207
246	Scientific and controlling instruments; Opcial and health service supplies	569,968	0.278	0.109	0.427	0.208
311	Farm machinery and equipment	107,989	0.106	0.023	0.271	0.208

626	Misc. general merchandise stores and Sewing, needlework, and piece good stores; Department stores and mail order houses; Vending machine operators; Direct selling establishments	2,582,052	0.127	0.023	0.220	0.209
462	Eletric and gas, and other combinations	159,951	0.267	0.118	0.428	0.210
121	Misc. food preparations and kindred products	199,311	0.112	-0.023	0.134	0.211
432	Services incidental to transportation	361,012	0.287	0.054	0.580	0.211
212	Misc. plastic products	500,365	0.124	0.028	0.160	0.212
856	Colleges and universities; Elementary and secondary schools; Child and day care services; Museums, art galleries, and zoos; Libraries	9,676,908	0.569	-0.006	0.290	0.214
122	Not specified food industries	2,649	0.780	0.780	0.412	0.217
646	Motor vehicle dealers; Auto and home supply stores; Misc. vehicle dealers and mobile home dealers	1,622,942	0.097	0.017	0.296	0.223
42	Crude petroleum and natural gas extraction	368,264	0.299	0.054	0.379	0.224
630	Apparel and accessory stores, except shoe	758,754	0.155	0.021	0.115	0.224
581	Hardware stores	175,544	0.122	0.003	0.200	0.225
471	Sanitary services	273,758	0.137	0.082	0.101	0.226
470	Water supply and irrigation	211,294	0.104	-0.003	0.209	0.227
712	Real estate; including real estate-insurance-law offices	1,986,342	0.310	0.075	0.345	0.229
541	Drugs, chemicals, and allied products wholesale	224,014	0.427	0.155	0.340	0.230
206	Household appliances; Radio, TV and Communications equipment; Electric machinery , equipment and supplies, n.e.c., Not specified electrical machinery, equipment and supplies.	2,039,326	0.259	0.098	0.361	0.232
592	Variety stores	117,805	0.100	0.031	0.096	0.233
442	Telegraph and misc. communication services & Radio television and broadcasting	462,762	0.355	0.081	0.463	0.234
631	Shoe stores	150,307	0.135	0.042	0.139	0.242
696	Farm supplies & Retail nurseries and garden stores; Misc. retail stores; Sporting goods, bicycle and hobby stores; Book and stationery stores	1,483,570	0.208	0.025	0.145	0.249
550	Groceries and related products wholesale	762,392	0.154	0.037	0.165	0.249
826	Offices of physicians, dentists, chiropractors, optometrists, health practitioners, n.e.c.; Nursing and personal care facillities; Health services n.e.c., Job training and voc rehab services	4,789,832	0.301	0.015	0.139	0.251
161	Misc. paper and pulp products	205,650	0.165	0.013	0.207	0.252
380	Photographic equipment and supplies	127,104	0.329	0.101	0.469	0.254
710	Security, commodity brokerage, and investment companies	665,920	0.568	0.105	0.599	0.256
362	Guided missiles, space vehicles, and parts, Ordnance, and Aircraft and parts	1,158,906	0.325	0.085	0.493	0.257
890	Accounting, auditing, andd bookkeeping services	598,721	0.552	0.009	0.638	0.266
346	Plastics, synthetics, and resins; Soaps and cosmetics; Agricultural Chemicals; Industrial and miscellaneous chemicals.	969,798	0.266	0.054	0.377	0.269
441	Telephone (wire and radio)	1,060,821	0.219	0.097	0.600	0.270
120	Beverage industries	237,593	0.206	0.070	0.202	0.274
571	Not specified wholesale trade	25,936	0.518	0.362	0.064	0.274
141	Floor coverings, except hard surfaces	71,606	0.069	-0.011	0.247	0.275
190	Paints, varnishes, and related products	67,751	0.218	-0.018	0.234	0.276
542	Apparel, fabrics, and notions wholesale	129,166	0.321	0.080	0.282	0.277

162 Paperboard containers and boxes	197,127	0.114	0.025	0.107	0.281
172 Printing, publishing, and allied industries except newspapers	1,319,340	0.236	0.068	0.245	0.287
400 Railroads	296,793	0.108	0.034	0.212	0.292
632 Furniture and home furnishings stores	512,247	0.155	0.013	0.117	0.292
691 Not specified retail trade	23,782	0.404	-0.056	0.232	0.293
881 Membership organizations	485,262	0.347	0.089	0.322	0.302
831 Hospitals	4,653,470	0.341	0.100	0.330	0.303
460 Electric light and power	701,867	0.218	0.036	0.342	0.304
140 Dyeing and finishing textiles, except wool and knit goods	31,517	0.117	0.066	0.132	0.306
640 Household appliances, TV, and radio stores	512,181	0.218	0.082	0.379	0.308
736 Misc. Personal services; Misc. Business services; Computer and data processing services; Detective and protective services; business services, n.e.c.;	4,919,872	0.370	0.047	0.362	0.311
800 Theaters and motion pictures	460,247	0.409	0.153	0.170	0.313
252 Structural clay products	45,428	0.051	-0.035	0.029	0.319
500 Motor vehicles and equipment wholesale	212,794	0.165	0.002	0.285	0.327
551 Farm products, raw materials wholesale	86,208	0.230	0.111	0.110	0.327
472 Not specified utilities	6,334	0.245	0.132	0.325	0.334
130 Tobacco manufactures	42,330	0.291	0.197	0.135	0.335
882 Engineering, architectural, and surveying services	865,606	0.521	0.024	0.439	0.336
711 Insurance	2,387,822	0.349	0.085	0.537	0.339
876 Religious organizations; Residential care facillities, without nursing; Social services, n.e.c.	1,942,100	0.412	0.016	0.131	0.342
642 Drug stores	507,289	0.294	0.028	0.272	0.348
901 All public administration	5,459,039	0.323	0.052	0.386	0.355
580 Lumber and building material retailing	483,765	0.115	0.017	0.146	0.362
160 Pulp, paper, and paperboard mills	331,060	0.144	0.033	0.233	0.364
536 Electrical goods; Hardware, plumbing and heating supplies wholesale	526,161	0.218	0.035	0.339	0.371
721 Advertising	263,491	0.501	0.093	0.340	0.375
461 Gas and steam supply systems	199,142	0.190	0.051	0.298	0.380
101 Dairy products	172,164	0.122	0.036	0.128	0.430
841 Legal services	1,174,849	0.582	0.036	0.355	0.435
602 Diary product stores	44,560	0.193	0.137	0.000	0.575
422 Pipe lines, except natural gas	15,967	0.367	0.146	0.043	0.601

Notes. College employment levels and changes are calculated from the CPS Merged Outgoing Rotation Groups for 1980 and 1990 and include all individuals ages 18 - 65 in paid employment (both wage and salary and self-employed workers) during the survey reference week. Computer use frequencies and changes are drawn from the October 1984 and October 1993 Current Population Surveys using the same inclusion criteria as above. Industry employment levels in 1990 are estimated using CPS sampling weights.

Appendix Table A3: OLS First-Difference Estimates of the Relationship Between Computerization 1984 - 1993 and Growth in the College Workforce Share in 3-Digit Industries 1960 - 1995. ***(Dependent variable: 100 * Annual Change in College Workforce Share)***

	Census - Census 1960 - 1970			Census - Census 1970 - 1980			CPS - CPS 1980 - 1990			CPS Feb. 90 - CPS 95 1990 - 1995		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Δ Computer Use 1984-93	.011	.077	.033	.155	.223	.167	.159	.215	.110	.261	.355	.268
	(0.019)	(0.023)	(0.021)	(0.024)	(0.028)	(0.026)	(0.034)	(0.042)	(0.033)	(0.059)	(0.073)	(0.074)
Mean Ed '60		-.006	-.009		-.006	-.010		-.005	-.011		-.008	-.012
		(0.001)	(0.001)		(0.002)	(0.001)		(0.002)	(0.002)		(0.004)	(0.004)
Computer Use '84			.081			.091			.173			.135
			(0.012)			(0.014)			(0.017)			(0.037)
Intercept	.066	.592	.858	.140	.692	.943	.033	.462	.900	-.355	.363	.678
	(0.043)	(0.119)	(0.111)	(0.056)	(0.144)	(0.133)	(0.078)	(0.209)	(0.163)	(0.138)	(0.362)	(0.358)
R-Squared	.003	.141	.351	.225	.310	.470	.138	.168	.532	.123	.152	.226
n	140	140	140	140	140	140	140	140	140	140	140	140
Weighted Mean Change	.088	.088	.088	.465	.465	.465	.371	.371	.371	.207	.207	.207

Notes: Standard errors are in parentheses. Computer use is measured as 10 times the change in industry computer use frequency between 1984 and 1993 as reported in the October 1984 and 1993 CPS. College workforce shares are measured as the share of industry workers with 16+ completed years of schooling and as the share of industry workers holding at least a B.A. in 1990 - 1995 changes. Levels variables (mean education and computer use frequency in 1984) are multiplied by 10. 1960-1970 and 1970-1980 changes use data from the 1960, 1970, and 1980 Census PUMS. 1980 to 1990 changes use data from the 1980 and 1990 CPS Merged Outgoing Rotation Group files. 1990-1995 CPS-CPS changes use data from the February 1990 CPS and the 1995 CPS Merged Outgoing Rotation Groups. Industries are coded as 140 consistent CICs, spanning the 1960, 1970, 1980, and 1990 CIC standard. All regressions are weighted by the product over the sum of the industry share of total employment in each of the two years used in constructing the dependent variable. See the data appendix for details.

Appendix Table A4: Capital and Computer Measures 1960 - 1990: Levels and 100 * Annual Log Changes in Non-agricultural, Predominantly Private Sector Industries.

	All Sectors				Manufacturing				Non-Manufacturing			
Panel A: Levels by Decade	**1960**	**1970**	**1980**	**1990**	**1960**	**1970**	**1980**	**1990**	**1960**	**1970**	**1980**	**1990**
OCAM/Capital Stock	0.004	0.003	0.010	0.046	0.003	0.003	0.009	0.040	0.004	0.003	0.010	0.049
OCAM/FTEE	0.072	0.064	0.332	2.545	0.073	0.063	0.317	1.986	0.071	0.064	0.341	2.817
Capital Stock/FTEE	42.67	54.94	72.01	86.33	25.98	33.60	47.22	59.29	56.10	70.09	87.42	99.44
Panel B: 100 * Annual Log Changes		**60-70**	**70-80**	**80-90**		**60-70**	**70-80**	**80-90**		**60-70**	**70-80**	**80-90**
OCAM/Capital Stock		-4.81	11.35	16.96		-3.68	11.88	14.80		-5.65	10.99	18.14
OCAM/FTEE		-1.40	13.66	18.82		-0.23	15.22	17.58		-2.28	12.62	19.50
Capital Stock/FTEE		3.41	2.31	1.86		3.45	3.34	2.78		3.37	1.63	1.36

Notes. Figures are tabulated for the 41 National Income and Product Accounts (NIPA) non-agricultural, predominantly private-sector industries (20 in manufacturing, 21 in non-manufacturing) found in Table 8. Capital measures and FTEES are drawn from the National Income and Product Accounts (NIPA). Each measure is a five year centered average of the respective variable (except for FTEEs). FTEEs are measured in thousands. Capital measures are in millions of constant 1987 dollars. OCAM is Office Computing and Accounting Machinery. All stock variables are net stock measures. Panel B is calculated as the 100 times the annual change in the log of each of the variables in panel A during the indicated 10 year period. Figures in Panel A are weighted by industry share in the total wage bill in each year. Figures in Panel B are weighted by the product over the sum of the industry share of the total wage bill in each of the two years used in calculating the measure. See the data appendix for details.