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Wage Dispersion in the 1980s: Resurrecting the Role of Trade Through the Effects of Durable Employment Changes

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Abstract

This paper finds that changes in durable manufacturing employment and investment in computer equipment can explain rising wage dispersion in the United States, measured in terms of the education premium. Reduced employment opportunities in durables production drive down the average wage for workers with only a high school education, thereby increasing the wage premium for college education. An innovation in this paper is the inclusion of investment in equipment as a proxy for skill-biased technical change. The rise in the technical skill premium could alone explain all of the rise in the college premium since 1979 were there no offsetting effects.

JEL Classification Numbers: J30, J31

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Summary

Although a substantial literature has documented rising wage inequality in the United States, a consensus on the causes of increased wage disparity has not been achieved. Some of the strongest statistical evidence has been presented by Borjas and Ramey (1994a, 1994b), who find that the trade deficit in durable manufactures alone can explain over 90 percent of movements in wage differentials between college and high school graduates.

This paper unbundles the effect of durables trade on wage inequality, as captured by Borjas and Ramey, into employment and rent effects. It finds a strong causal relationship between employment in durables manufacturing and both the education differential and the standard deviation of wages. The real effective exchange rate, which we use to measure changes in the competitiveness of U.S. industry, plays a significant, although smaller role in explaining the education differential. Using durables employment and the real effective exchange rate and controlling for computerized investment and the supply of college graduates, we obtain a strong cointegrating relationship with the education differential.

The importance of durables employment in explaining the education differential shows that the changing industrial composition of the economy is an important factor in wage dispersion. This paper also analyzes the standard deviation of wages across two-digit industries, which has risen 50 percent since 1970 or twice as rapidly as the education differential. The empirical results demonstrate that declining employment in durables manufacturing plays a major role in rising interindustry wage dispersion in the short run, as workers who are laid off from durable goods industries find work at the lower tail of the wage distribution and hence raise interindustry wage dispersion. In the long run, declining employment in durables manufacturing lowers interindustry wage dispersion because premium wages in durable goods industries are bid down; rising labor force participation has offset this effect to increase total dispersion.

The analysis represents two innovations in the wage dispersion literature: use of the Johansen-Juselius cointegration technique and an explicit measure of technological progress in the workplace.

I. Introduction

Although a substantial literature has documented rising wage inequality in the United States, consensus regarding the causes of increased wage disparity has not been achieved. Some of the strongest statistical evidence has been presented by Borjas and Ramey (1994a,b), who find that the trade deficit in durable manufactures alone can explain over 90 percent of movements in wage differentials between college and high school graduates. They assert that increasing international competition in durables production, as proxied by the trade deficit in durable goods, has reduced both wage premia and the number of workers in durable manufacturing, thereby bringing down the average wage of workers with only high school education and increasing the education premium. While the correlation that they establish is strong, it leaves unexplained the channels of transmission that reduce the relative wage of workers without higher education.

This paper unbundles the effect of durables trade on wage inequality captured by Borjas and Ramey, separating out employment and rent effects. We find a strong causal relationship between employment in durables manufacturing and both the education differential and the standard deviation of wages. The real effective exchange rate, which we use to measure changes in the competitiveness of U.S. industry, plays a significant, although smaller, role in explaining the education differential. Using durables employment and the real effective exchange rate, and controlling for computerized investment and the supply of college graduates, we obtain a cointegrating relationship with the education differential that is more powerful statistically than Borjas and Ramey's specification using trade in durables. Moreover, the addition of trade in durables to our specification does not yield an economically meaningful cointegrating vector. The same variables are similarly successful in explaining the wage differential between college graduates and high school dropouts.

The importance of durables employment in explaining the education differential shows that the changing industrial composition of the economy is an important factor in wage dispersion. To identify the importance of this effect, this paper also analyzes the standard deviation of wages across two-digit industries. This measure of interindustry wage inequality has risen twice as fast as the education differential, increasing 50 percent since 1970. Our empirical results demonstrate that declining employment in durables manufacturing is a major factor in rising interindustry wage dispersion in the short run, as workers who are laid off from durables goods industries find work at the lower tail of the wage distribution and hence raise interindustry wage dispersion. In the long run, declining employment in durables manufacturing lowers interindustry wage dispersion because premium wages in durable goods industries are bid down. The major cause of the rise in interindustry wage dispersion in the long run is the sharp rise in the number of women as a proportion of the labor force.

Our analysis represents two innovations in the wage dispersion literature: use of the Johansen-Juselius cointegration technique and an explicit measure of technological progress in the workplace. The Johansen-

Juselius technique enables one to identify all possible cointegrating relationships and provides a test to evaluate the statistical significance of the nonstationary regressors, unlike the more common Engle-Granger approach. We employ real investment in computerized technologies as a means of quantifying skill-biased technical change in the workplace, cited in several studies as the primary source of increased education differentials. Although the recent skill-bias in technical change has been associated with computers and information technology, previous studies of wage trends have treated technical change as a residual or proxied it with a time trend.

The paper is organized in five parts. Section I reviews the literature on the causes of rising skill-based wage inequality and presents the analytical framework for our empirical work on education differentials. Section II discusses sources of change in the interindustry wage structure. The Johansen-Juselius cointegration methodology is then presented in section III. Sections IV and V present empirical results using the education differential and standard deviation of industry wages, respectively. Section VI concludes.

II. Sources of Skill-Based Wage Inequality

The wage differential between college graduates and high school graduates rose from 38 percent in 1980 to 53 percent in 1990 and the wage differential between college graduates and high school dropouts rose from 66 percent to 86 percent. Chart 1 presents this rise using the natural logarithm of average weekly earnings adjusted for experience from the annual demographic files of the Current Population Survey. The rise in the education premium during the eighties contrasts with its decline during the seventies when the baby-boom generation entered the labor force and the supply of college graduates increased rapidly.

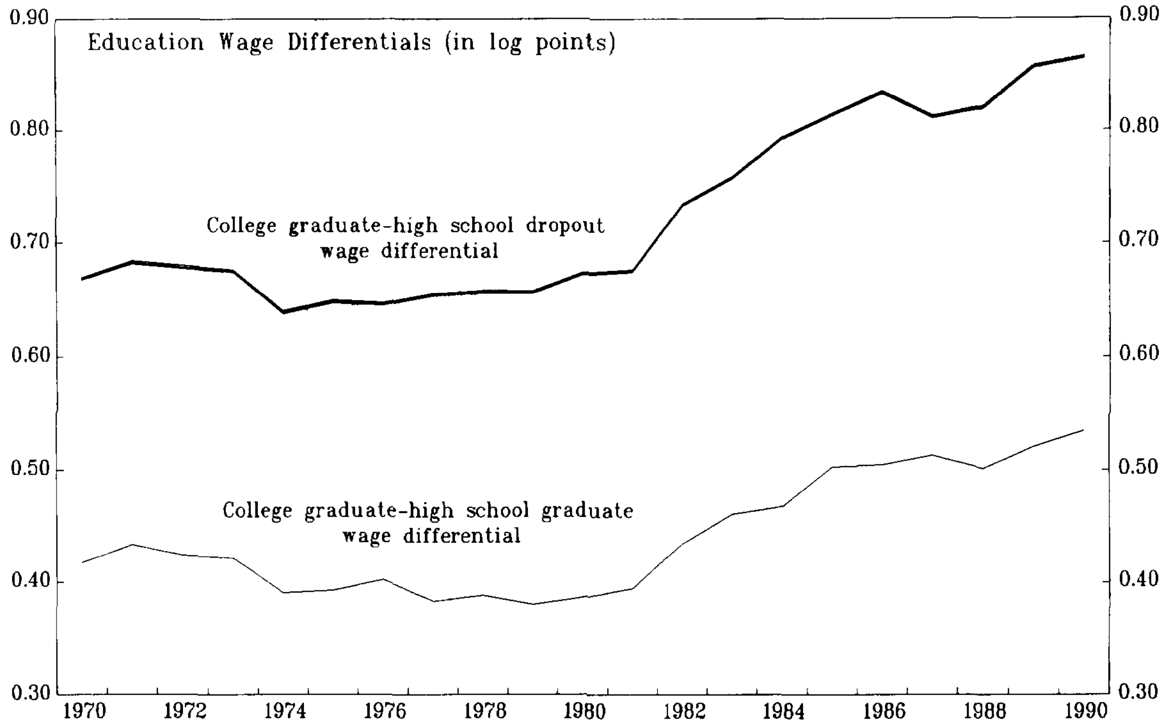
In the many recent papers that seek to explain the rising education premium, the most often-cited causes include declining manufacturing employment (Katz and Murphy, 1992; Murphy and Welch, 1991), loss of blue-collar wage premia due to declines in both manufacturing employment and union power (Blackburn, Bloom, and Freeman, 1990; Bluestone and Harrison, 1988), the impact of technology (Bartel and Lichtenberg, 1987; Davis and Haltiwanger, 1991; Krueger, 1994; Mincer, 1989, 1991), and slower growth of the college-educated population in the 1980s (Katz and Murphy, 1992; Murphy and Welch, 1989). The decline in manufacturing employment and blue collar wages have generally been associated with increased import penetration in these sectors and the United States' reduced global market share in traditional high-wage industries.

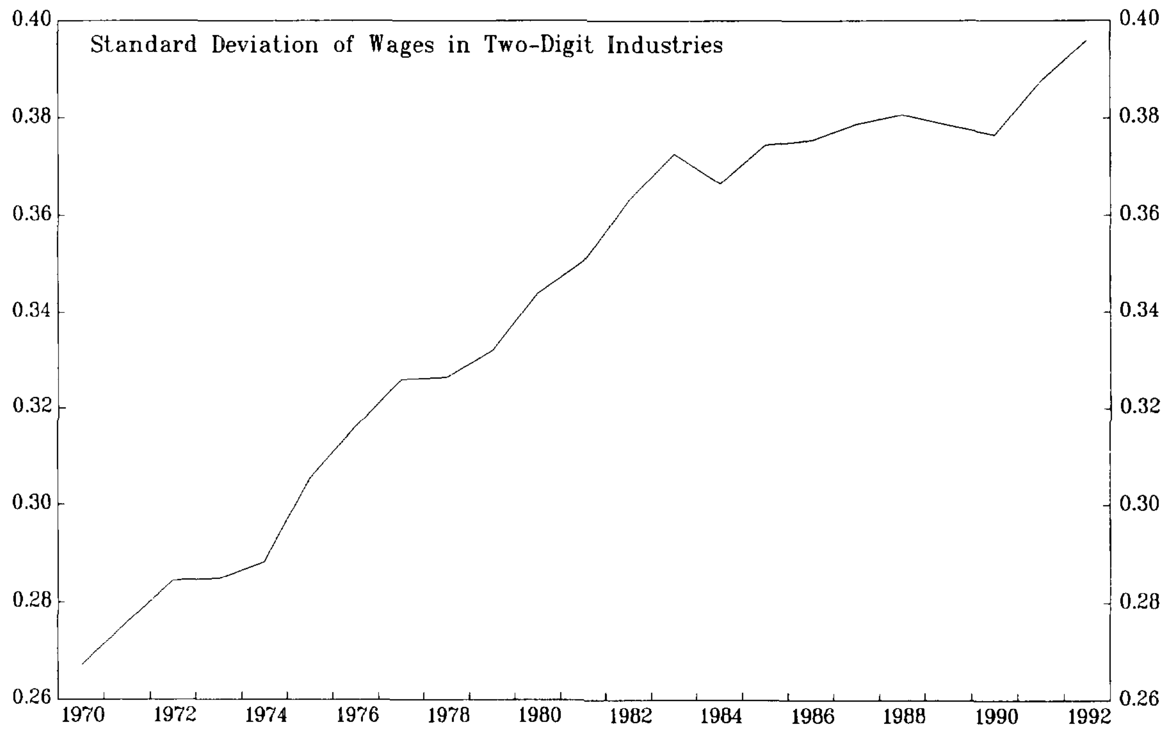
The relative strength of these four competing theories has been tested by Bound and Johnson (1992), who decompose changes in relative wages and determine technological change to be the principal cause of increasing education and age differentials and narrowing gender differentials. They find that economy-wide, technological change led to faster growth in the wages of the highly educated and of women, and slower wage growth for young

CHART 1

UNITED STATES

WAGES





workers with a high school diploma or less. The data also reveal a major shift in four premium-wage blue-collar industries (durables/mining, non-durables, transportation, and public utilities) toward employing more educated workers and, among workers without college education, toward older workers. Bound and Johnson argue that turnover is low in these high-wage industries and the declining demand for less-educated workers was managed by hiring few young workers while experienced workers retained their jobs. 1/

A related debate has arisen concerning the relationship between trade and wage dispersion, with opinion in the economics profession evenly divided as to whether a causal relationship exists. Krugman and Lawrence (1993) argue that under the hypothesis of factor price equalization, a skill-abundant country will shift its production toward skill-intensive sectors and away from labor-intensive sectors. This will induce a rising skill-based wage differential and lead firms in all industries to reduce the ratio of skilled to unskilled workers. However, between 1979 and 1989 the ratio of skilled workers to unskilled workers has risen in nearly all manufacturing industries and therefore Krugman and Lawrence discount any relationship between trade and wage dispersion. Leamer (1994) believes that the factor price equalization theorem does not hold in the United States and suggests using the Stolper-Samuelson theorem in analyzing the relationship between trade and wage dispersion. The Stolper-Samuelson theorem states that a decline in the price of products made intensively by low-skilled workers lowers their relative wage but does not necessarily affect factor input ratios. Lawrence and Slaughter (1993) discount Leamer's assertion of a decline in the price of products made intensively by low-skilled workers by showing a rise in the relative import and export prices of unskilled labor-intensive goods. Sachs and Shatz (1994) have carried out a similar analysis excluding the effect of computers, arguing that computer prices are difficult to measure. They find a negative--although statistically insignificant--relationship between relative import and export prices and skill intensity.

Borjas and Ramey posit that increased international competition in durables is the dominant factor in explaining rising wage differentials. They show that the null hypothesis of non-cointegration with the education differential can be rejected with 96 percent confidence for the durables deficit and, decomposing the durables deficit into the ratios of imports and exports to GDP, they find that imports have a stronger impact on the education differential. They also show that the null hypothesis of no cointegration cannot be rejected for any of the following variables, taken individually: the relative supply of college and high school graduates, the relative supply of college graduates and high school dropouts, the unemployment rate, the nonunionization rate among workers, the percentage of immigrants in the labor force, the female labor force participation rate,

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1/ Looking simply at the wage differential between older and younger workers without college may exaggerate the difference, as a larger share of older workers hold jobs in premium wage, typically highly unionized industries.

and spending on research and development per labor force participant. On this basis, Borjas and Ramey argue that these other factors are not significant causes of rising wage dispersion. In addition, Borjas and Ramey reject the importance of technological change as the residuals from their regressions are not autocorrelated and thus do not resemble rising technological levels.

Despite the strong empirical relationship between the durables deficit and the education differential, Borjas and Ramey's analysis has two significant weaknesses. First, the durables deficit cannot directly cause rising differentials, rather it must be proxying other trends in the economy such as changes in durable manufacturing wages or employment in durables manufacturing that would alter the relative wages of the groups. Borjas and Ramey cite two possible effects, both the result of increased international competition: declining durables employment and declining rents in durables manufacturing, both leading to lower wages. Real wage trends suggest, moreover, that the latter may be counterfactual: the real wage premium in durable manufacturing has risen over 1970-92, not fallen, although declining wages at the bottom of the distribution may have pulled the average down. Second, Borjas and Ramey do not control for other effects on the wage differential such as the supply of college graduates or technological change.

This paper seeks to address the two weaknesses of Borjas and Ramey's approach as follows. First, the paper unbundles the effect captured by Borjas and Ramey in the durables deficit by identifying channels that directly affect wages and, second, the paper includes variables that proxy for the supply of college graduates and changes in technology. The long-run competitiveness of U.S. durable goods industries should be a function of relative prices in a common currency. Real exchange rate fluctuations influence movements in producers' profit margins and eventually wages in durable goods industries adjust to enable firms to recover their profit margins, assuming no change in industry or labor market structure. Real exchange rate fluctuations also affect durable employment levels and the resulting displacement of workers puts downward pressure on wages in lower-paying industries, thereby indirectly increasing wage dispersion.

These effects can be seen in a simple model of three industries, one employing college graduates to provide services and the other two employing high-school graduates to produce durable goods and services respectively. The two industries that employ high-school graduates differ in terms of their exposure to foreign competition. We assume that the durable goods industry must compete with foreign suppliers so that its labor demand function depends on relative prices in a common currency. In contrast we assume that the service industry does not trade internationally and therefore its labor demand only depends on its wage. Workers are substitutable between the durable goods and service industries but not between the high school and college graduate industries.

We now specify the demand and supply curves in each industry. Assume that the demand for the services provided by college graduates (D_{1t}) can be expressed as

$$D_{1t} = L_{d1}e^{\alpha t} / (w_{1t}/p_t) \tag{1}$$

where α represents skill-biased technological change. L_{d1} is a constant and w_{1t}/p_t is the real wage in the high-skill service industry. We assume that the demand for college-educated labor and skill-biased technological change are complements.

The supply of college-educated labor (S_{1t}) is

$$S_{1t} = L_{s1}e^{\beta t} \tag{2}$$

where β indicates the growth of the college-educated population and L_{s1} is a constant. In equilibrium, supply equals demand and therefore the change in the log wage can be expressed as

$$\Delta(w_{1t}/p_t) = \alpha - \beta. \tag{3}$$

The profile of the college-educated wage depends on the speed of technological change relative to the growth in the supply of college graduates.

The demand for durable goods industry workers (D_{2t}) is assumed to depend negatively on both the real effective exchange rate $REER_t$ (a rise in REER represents appreciation) and the real wage in the durable goods sector (w_{2t}/p_t):

$$D_{2t} = 1/(REER_t(w_{2t}/p_t)) \tag{4}$$

The real effective exchange rate can be expressed as

$$E_t = L_{d2}e^{\gamma t} \tag{5}$$

where L_{d2} is a constant and γ is the rate of change in the real effective exchange rate.

The supply of durable goods workers (S_{2t}) is

$$S_{2t} = (w_{2t}/p_t)^{\lambda} \tag{6}$$

where λ is the elasticity of supply of durable goods workers. We assume that unions restrict entry into this industry so that a positive wage differential between durable goods wages and service wages may exist. The equilibrium change in the log wage is

$$\Delta\ln(w_{2t}/p_t) = -\gamma/(1+\lambda) \tag{7}$$

and the equilibrium change in supply is

$$\Delta\ln(S_{2t}) = -\lambda\gamma/(1+\lambda). \tag{8}$$

Assuming that low-skill service workers provide non-traded goods, the demand for service workers (D_{3t}) is based only on the wage, w_{3t},

$$D_{3t} = 1/(w_{3t}/p_t) \tag{9}$$

The supply of low-skill service workers (S_{3t}) is directly related to the change in the supply of durable goods workers ($\Delta\ln S_{2t}$) because we assume that durable goods workers can obtain employment in the service industry;

$$S_{3t} = S_{3(t-1)}[1-(S_{2(t-1)}/S_{3(t-1)})(\lambda\gamma/1+\lambda)]. \tag{10}$$

The wage in the low-skill service industry is market-clearing and therefore falls when durable goods workers are laid off and seek work in the low-skill service sector:

$$\Delta\ln(w_{3t}/p_t) = -(S_{2(t-1)}/S_{3(t-1)})(\lambda\gamma/1+\lambda). \tag{11}$$

The model illustrates how three kinds of shocks to the economy may have affected the distribution of wages in the last 20 years: skill-biased technological change (α), an increase in the supply of college-educated workers (β), and the extended appreciation of the dollar real exchange rate through 1985 (γ). First, we assume that the economy has experienced a persistent technological bias in favor of college-educated workers which has raised the relative demand for these workers. Equation 1 shows how an increase in α or skill-biased technical change, would increase demand for these workers. We use investment in computer, office, and communications equipment as a proxy for the rate of technical innovation and the impact of technology in workplaces, making the assumption that it is correlated with the introduction of computerized production machinery (for which separate data are not available). Generally, skill-biased technical change is associated with increased use of computers and information technology in the workplace (Krueger, 1991; Dunlop Commission, 1994). Prior to the advent of computers, Nelson and Phelps (1966) argued that the relative demand for highly-educated workers should rise during periods of rapid technical change because of their ability to adapt to new methods.

The positive demand effect from skill-biased technological change may, however, be offset by the rise in the supply of college graduates, represented in the model as an increase in β (equation 2) the net impact is uncertain, as equation (3) shows. The supply effect was particularly strong in the 1970s when the education premium actually declined in response to a large increase in the supply of college graduates. We therefore expect a negative response of the education differential to the supply of college graduates.

The third shock that the model illustrates is the real appreciation of the U.S. dollar through 1985. Chart 2 presents a real effective exchange rate series produced by J.P. Morgan, which incorporates 22 OECD countries and 23 developing countries. The real exchange rate appreciated by more than 35 percent over 1980-85 alone, then declined nearly 30 percent to 1988. In terms of the model, the prolonged appreciation of the exchange rate lowered the competitiveness of U.S. products putting downward pressure on the demand for labor in durable goods industries (equation 4) and should have led to declines in both wages and employment in this sector. The displaced workers would find new employment in the service sector, lowering the wage in this sector.

The implications of the model lead us to emphasize changes in durables employment (*demp*) and the real exchange rate (*reer*) as inducing changes in the college-high school differential, w_{hs}, and college-dropout differential, w_{dp}. We control for the effects of changes in the supply of college-educated workers and technology with variables that measure the ratio of college-educated workers (*cgrad*) and real investment in computers and computerized office equipment *(compi)*. 1/ Section III will present estimates of the following specification:

$$w_{hs} = \alpha_0 + \alpha_1 demp_t + \alpha_2 reer_t + \alpha_3 cgrad_t + \alpha_4 compi_t + \epsilon_t \quad (12)$$

$$w_{dp} = \alpha_0 + \alpha_1 demp_t + \alpha_2 reer_t + \alpha_3 cgrad_t + \alpha_4 compi_t + \epsilon_t \quad (13)$$

1/ For precise variable definitions, refer to the data annex.

The wage gap between high school dropouts and college graduates should be affected by the same factors as the gap between high school and college graduates. Skill-biased technological change would, however, be expected to hurt high school dropouts more than diploma holders because the former have lower skills and are less substitutable for college graduates. In addition, the range of high-wage jobs available to dropouts presumably is and has always been narrower than that for diploma holders. Thus, the loss of durable manufacturing jobs would likely hurt the average wage of dropouts more than that of high school graduates.

III. Sources of Change in the Interindustry Wage Structure

The importance of employment in durables manufacturing in explaining the college-high school differential seems to confirm the role of the changing industrial composition of employment in generating wage dispersion. As a result, we also examine changes in the standard deviation of two-digit industry wages relative to an employment-weighted average wage, over 1970-92. 1/ The standard deviation of wages captures the structure of relative wages across industries, which studies have found to be stable across occupations, countries, and, within the United States, across heavily and weakly unionized regions (Katz and Summers, 1988; Krueger and Summers, 1988; Dickens and Katz, 1987). Yet, like other measures of wage dispersion, the standard deviation of wages has trended upward over the past two decades, rising from 26 percent in 1970 to 39 percent in 1992 (Chart 1). However, unlike the profile of the education differential, most of the increase in the standard deviation of wages occurred in the seventies, while the profile has remained relatively flat in the eighties.

Our specification for the standard deviation of industry wages is similar to the specification for the college-high school wage differential except that we substitute the participation of females as a share of the labor force (*flf*) for the labor supply of college graduates. 2/

$$\sigma_{ind} = \beta_0 + \beta_1 demp_t + \beta_2 reer_t + \beta_3 flf_t + \beta_4 compi_t + \epsilon_t \qquad (14)$$

Employment in durable goods manufacturing may have a negative short-run effect on the standard deviation of wages but a positive long-run effect. In the short run, wages in the highly-unionized durable goods industries should be sticky because they are predetermined by union contracts, not market-clearing. As a result, the appreciating exchange rate will first induce a decline in manufacturing employment rather than a change in the durable wage. This will increase the supply of labor displaced from durable manufacturing and available to lower wage sectors (which tend not to be

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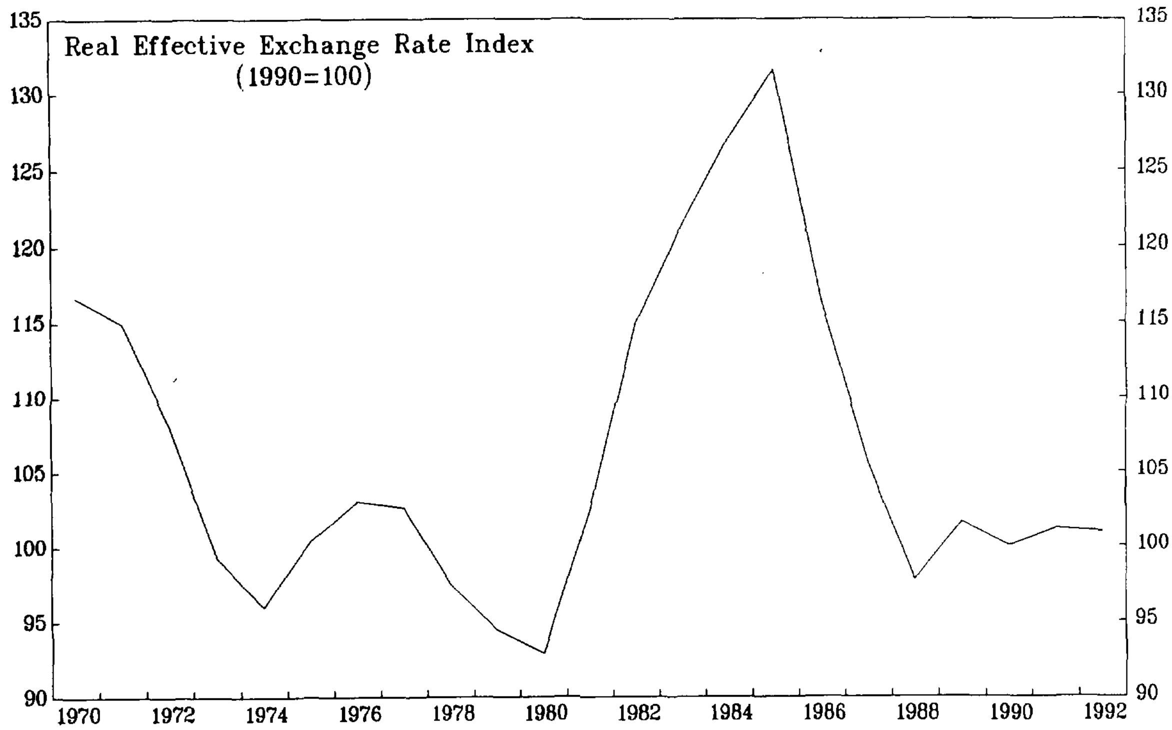
1/ The two-digit industries analyzed are in manufacturing, transportation and communication, wholesale and retail trade, and private service sectors.

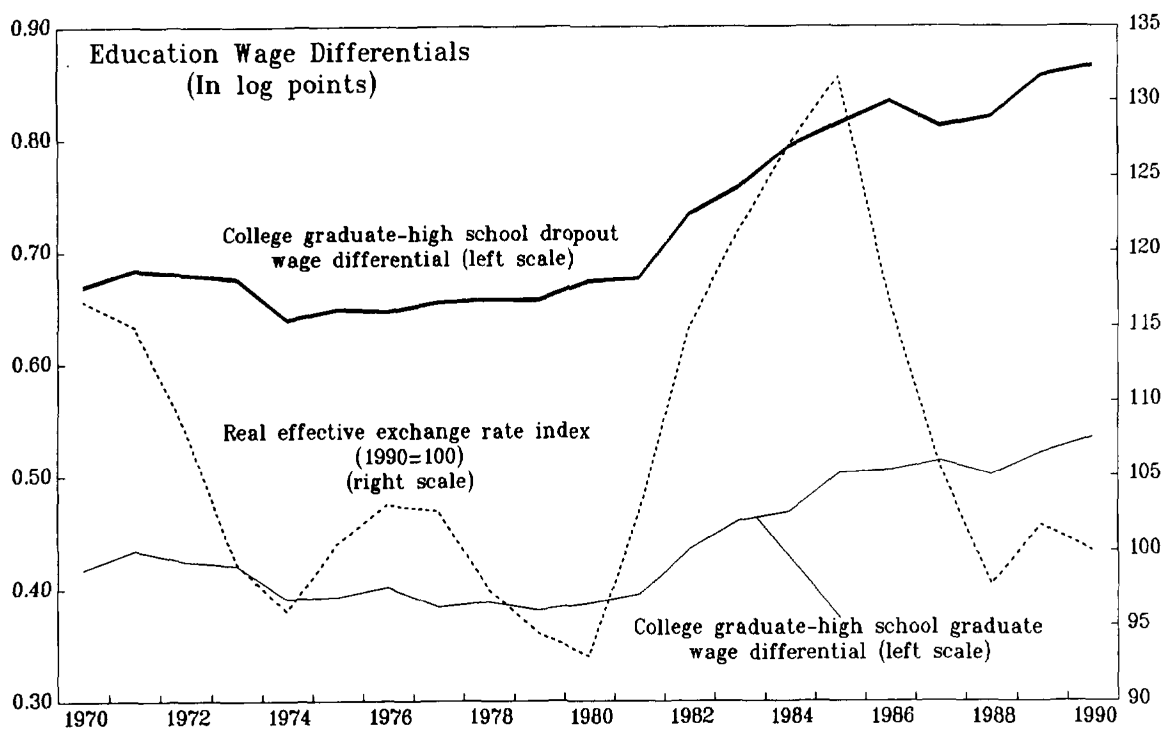
2/ For precise variable definitions, refer to the data annex.

CHART 2

UNITED STATES

REAL EFFECTIVE EXCHANGE RATE AND EDUCATION WAGE DIFFERENTIALS





unionized and therefore have market-clearing wages) and will drive down wages in those industries. The average wage will also fall as a result, but less than one-for-one, causing the standard deviation of wages to rise. In the long run, declining employment in durables manufacturing will drive down real wages in the sector and, since durable wages are among the highest, the standard deviation of wages will fall as a result.

The growth in the labor supply of women is expected to have a positive effect on the standard deviation of wages because women tend to be employed in low-wage sectors. The increased labor supply available to these sectors will drive down wages in sectors already paying less than the employment-weighted mean, and thereby increase the standard deviation of wages.

Although the impact of skill-biased technological change on the standard deviation of wages across industries is difficult to predict, we expect the effect to be negative. Again, computer, office and communications investment proxies the introduction of new technologies into the workplace. Low wage sectors tend to be service sectors, where a greater proportion of capital is due to computers (versus heavy machinery). As a result, equal investments in computer technology would likely produce a greater increase in labor productivity and wages in service-producing than goods-producing industries. By bringing up the wages of low-wage sectors, computer investment would reduce the standard deviation of wages across industries.

IV. The Johansen-Juselius Cointegration Methodology

Our estimates of the determinants of the education differential use the Johansen-Juselius technique (Johansen, 1988; Johansen and Juselius, 1990), which permits the maximum likelihood estimation of all possible cointegrating relationships. The Johansen-Juselius technique also includes two likelihood ratio tests, with well-defined limiting distributions, to determine which cointegrating vectors are statistically significant and test linear restrictions on the parameters. These properties represent an improvement over other methods of cointegration analysis.

Our interest in using the Johansen-Juselius technique arises precisely because the education differential and standard deviation of wages are non-stationary series. The Z_ρ and Z_t test statistics presented in Table 1 indicate that we accept the null hypothesis that all series are I(1) with the exception of the Z_t statistic for the ratio of college graduates to the total labor force. 1/ We assume that all series are I(1) for the purpose of this analysis.

1/ The Z_ρ statistic corrects for serial correlation and heteroskedasticity in the estimation process whereas the Z_t statistic uses the OLS coefficient and adjusts the distribution of the test statistic for the presence of serial correlation and heteroskedasticity.

Cointegration analysis allows the estimation of long-run relationships between two or more nonstationary variables, provided they move closely together. Two or more nonstationary series are cointegrated if there exists a linear combination between them such that their difference is stationary. Because the difference is stationary, a regression including all the variables of a cointegrating vector will have a stationary error term, such that traditional OLS estimation is feasible. Stock (1987) demonstrated that, not only are OLS estimates of cointegrating vectors consistent, but they converge to the true parameter values more rapidly than estimates of stationary series; this property has been referred to as superconsistency.

The most common approach to estimating a relationship between cointegrated series has been to estimate the cointegrating vector with the Engle-Granger (1987) two-step procedure. The Engle-Granger procedure consists in an OLS estimate of the long-run relationship, followed by a unit root test on its residuals. However, this approach has several important weaknesses. Most importantly, in a regression with more than two variables, one cannot verify whether the estimated OLS vector represents a unique long-run relationship or whether there exist multiple cointegrating vectors. Moreover, the power of the known unit root tests to reject the null hypothesis of nonstationarity is considered to be weak. Due to bias in the standard errors of OLS estimates of long-run relationships, one cannot use t-statistics to evaluate the statistical significance of nonstationary independent variables.

The Johansen-Juselius technique considers the kth order vector autoregression (VAR) for X_t

$$X_t = \Pi_1 X_{t-1} + \ldots \Pi_k X_{t-k} + e_t \tag{15}$$

where X_t is a vector of N variables, each Π_i is an (NxN) matrix of parameters, and e_t is a vector of iid disturbances. This system can also be expressed as an error-correction model:

$$\begin{aligned} \Delta X_t &= \Gamma_1 \Delta X_{t-1} + \Gamma_2 \Delta X_{t-2} + \ldots \Gamma_{k-1} \Delta X_{t-k+1} + \Pi X_{t-k} + e_t \\ \Gamma_i &= -I + \Pi_1 + \ldots \Pi_i, \quad i = 1, \ldots k \\ \Pi &= -(I - \Pi_1 - \ldots \Pi_k) \end{aligned} \tag{16}$$

where ΠX_{t-k} is the only level term and contains all available information about the long-run relationships among the series in the data vector. As all other terms are clearly I(0), ΠX_{t-k} must be $I(0)$: either X_{t-k} must contain between one and $(N-1)$ cointegrating vectors or Π must be a zero matrix. The Johansen-Juselius technique identifies the cointegration coefficients contained in Π when Π has full rank r $(0 < r < p)$, which implies the existence of r cointegrating vectors. In this case Π can be decomposed into two distinct matrices α and β such that $\Pi = \alpha\beta'$ and $\beta' X_{t-k}$ is $I(0)$; the elements of the (Nxr) matrix β are the parameters of the cointegrating vectors.

The number of cointegrating vectors r can be determined by two likelihood ratio tests. The maximal eigenvalue test tests the null hypothesis of r or fewer cointegrating vectors against the alternative of $r+1$ vectors. The trace test uses the trace of the stochastic matrix to test the null hypothesis of r or fewer cointegrating vectors against the alternative of $r+1$ or more. Johansen (1988) presents the critical values for both tests for $r \leq 5$; MacDonald and Taylor (1993) have extended this to $r = 6$.

A weakness of the Johansen-Juselius approach is that if $r > 1$, one cannot conclusively determine which is the true cointegrating relationship. A rule of thumb is to consider first the vector with the highest eigenvalue. However, if this vector includes coefficients that are not economically meaningful, a vector with economically rational coefficients but a lower eigenvalue should be preferred.

V. Empirical Analysis of the Education Differential

Before arriving at our final specification,

$$w_{hs} = \alpha_0 + \alpha_1 demp_t + \alpha_2 reer_t + \alpha_3 cgrad_t + \alpha_4 compi_t + \epsilon_t \tag{12}$$

we estimated a specification including only the durables deficit and the underlying durables employment and rent factors,

$$w_{hs} = \alpha_0 + \alpha_1 demp_t + \alpha_2 reer_t + \alpha_5 ddef_t + \epsilon_t \tag{17}$$

and a broader specification controlling for computer investment and the supply of college graduates,

$$w_{hs} = \alpha_0 + \alpha_1 demp_t + \alpha_2 reer_t + \alpha_3 cgrad_t + \alpha_4 compi_t + \alpha_5 ddef_t + \epsilon_t \tag{18}$$

All estimates use annual data for 1970-1990 and the Johansen-Juselius multivariate maximum likelihood method. Phillips-Perron tests, shown in Table 1, were unable to reject the null hypothesis of a unit root for any of the variables. 1/

1/ For the proportion of college graduates in the labor force, the null hypothesis of the unit root is rejected with the Z_t test but not with the more powerful Z_ρ test. A look at the data, moreover, shows that the proportion of college graduates in the labor force has risen steadily over 1970-90.

For equation (17), we find one significant cointegrating vector between the three variables, but no vector produces coefficient estimates with economically sensible coefficient signs. The broader specification (equation 18) including the proportion of college-educated workers in the total labor force and real computer investment yields three linear combinations that are cointegrated with the college-high school differential but once again, no cointegrating vector produces estimates with economically sensible coefficient signs. The sign on the real exchange rate variable is economically correct (positive) in all of the cointegrating vectors with the highest eigenvalues, whereas the sign on the durables deficit is incorrect (negative rather than positive). It appears therefore that when we control for the effect of the supply of college graduates, and computer investment on the college high school wage ratio, the independent effect of the durables deficit disappears.

In light of the above results, we chose to eliminate the durables deficit from the analysis and test for a cointegrating relationship between the college-high school wage ratio and employment in durables, the real exchange rate, the supply of college graduates and computer investment, as in equation (12). Using Johansen's multivariate maximum likelihood method, we found that, according to the maximal eigenvalue test, the null hypothesis of $r < 3$ against $r = 4$ could not be rejected whereas the null hypothesis of $r < 3$ against $r > 4$ could not be rejected using the trace test (see Table 2). Therefore the tests indicate that there are three significant cointegrating vectors and we chose the vector with the correct economic signs for all variables.

The coefficient signs of the preferred long-run cointegrating vector indicate that a rise in durables employment relative to aggregate employment reduces the college-high school wage differential, as predicted by the model (Table 3). This effect is expected as durables manufacturing represents many of the highest paid jobs for high school graduates. The rise in the supply of college graduates lowers the differential because it puts downward pressure on the college wage. Over the past 20 years this effect has been mitigated by the rapid rise in computer investment and the associated rise in the premium paid to college graduates, who are the most intensive users of computers. Finally, the appreciation of the real effective exchange rate in the early eighties eroded the competitiveness of U.S. manufacturing, which has led to an erosion of the wage premium paid to durable workers and a rise in the education differential. All the variables in the long-run equation also help to explain short-run changes in the differential, although half of the coefficients are smaller in absolute value.

Using the estimated long- and short-run equations, we performed dynamic simulations to determine the factors that contributed to the rise in the college-high school wage differential from 1979 to 1990. Our simulations assume that the ratio of durables employment to aggregate employment was constant at its 1970-79 average, that the ratio of college graduates to total employment was constant at its 1970-79 average and that both computer investment and the real exchange rate remained at their 1970-79 average.

The results indicate that the dominant factors driving the 15 percent rise in the college-high school wage differential between 1979 and 1990 are the rise in computer investment and the decline in durables employment (see tabulation below.) For example, the combined rise in computer investment and the fall in durables employment were estimated to have increased the college-high school wage differential by about 37 percent. These effects more than outweighed the 22 percent decline in the college-high school wage differential caused by the rise in the supply of college graduates. 1/ The real effective exchange rate did not contribute anything to the rise in the wage differential because the real effective exchange rate was flat over the long run. These results suggest that most of the adjustment in the durables goods industry to the appreciation of the real effective exchange rate in the early eighties took place through employment changes rather than through wage changes.

Simulated Change in the College-High School Wage Differential
Between 1979 and 1990

Change in the wage differential	15.4
Owing to 2/	
Change in supply of college graduates	-22.3
Change in computer investment	14.8
Change in durables employment	22.0
Change in the real exchange rate	0.0
Residual	1.1

The wage differential between college graduates and high-school dropouts behaves similarly to the differential between college and high school graduates. 3/ Employment in durables manufacturing, the supply of college graduates, computer investment and the real exchange rate generate five cointegrating vectors with the wage differential between college graduates and high school dropouts and we chose the vector with correct economic signs (Table 4). As expected, the dropout differential is more sensitive to all shocks in both the long and short-run equations (Table 3).

In the short-run equation, the most distinctive difference from the equation for college-high school differential lies in the coefficients on information investment and the supply of college graduates. Both

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1/ Interestingly, the combined effect on the college graduate wage of the change in the supply of college graduates and technological change were negative. This is consistent with the decline in the real wage of college graduates over this period (see Juhn (1994) for details).
2/ Difference between the wage differential obtained by holding the particular explanatory variables constant at their average level in the 1970s and the wage differential in 1990.
3/ We will also refer to the college graduate-high school dropout wage differential as the dropout differential.

coefficients are nearly twice as large (0.21 versus 0.11 for the information investment variable and -0.48 versus -0.25 for the college graduate supply variable) in the dropout differential equation.

Simulations revealed a stronger combined effect of the rise in computer investment and the decline in durables employment on the college-dropout wage differential than on the college-high school differential (see tabulation below). These positive effects were offset by a stronger downward pull on the wage differential from the rise in the supply of college graduates.

Simulated Change in the College-Dropout Wage Differential
Between 1979 and 1990

Change in the wage differential	20.8
Owing to 1/	
Change in supply of college graduates	-25.9
Change in computer investment	22.1
Change in durables employment	25.8
Change in the real exchange rate	0.0
Residual	-1.6

VI. Empirical Analysis of Interindustry Wages

Using annual data over the period 1970-92 and Johansen's multivariate maximum likelihood method, we estimate the effect of durables employment, the real exchange rate, computer investment, and the proportion of women in the labor force on the standard deviation of industry wages. According to the maximal eigenvalue test, the null hypothesis of $r < 2$ against $r = 3$ cannot be rejected (Table 5). In addition, the null hypothesis of $r < 2$ against $r > 3$ cannot be rejected using the trace test. Both tests indicate the presence of two significant cointegrating vectors. The preferred vector was chosen on the basis of having economically correct coefficient signs.

The coefficient signs of the preferred long-run cointegrating vector indicate that a rise in durables employment relative to aggregate employment raises the standard deviation of wages because it puts upward pressure on wages in durable goods industries (these wages are at the upper end of the wage distribution, Table 6). The rise in the ratio of females in the labor force also raises the standard deviation because females generally hold low wage jobs. The rise in computer investment lowers the standard deviation because a number of service industries that are intensive users of computers are low paid. Finally, an appreciated real effective exchange rate also lowers the standard deviation because it lowers the rents of workers in

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1/ Difference between the wage differential obtained by holding the particular explanatory variables constant at their average level in the 1970s and the wage differential in 1990.

durable goods industries (whose wages are at the upper end of the wage distribution).

In the long-run equation, the dominant factor is the size of the female labor force, which has a strong positive effect on the standard deviation of wages. In the short-run equation, the coefficient on the change in durable employment becomes negative, consistent with sticky durables wages in the short run: displacement of workers from durables manufacturing would increase the supply of workers to low wage industries and drive down wages in those industries, while durables wages would not decline.

Dynamic simulations for the standard deviation of two-digit industry wages revealed that the rise in the labor force participation of women raised the standard deviation by over 25 percent, dominating the combined negative effects of the rise in computer investment, the appreciation of the real effective exchange rate, and the decline in durables employment (see tabulation below).

Simulated Change in the Standard Deviation of Two-Digit Industry Wages Between 1979 and 1990

Change in the standard deviation	4.5
Owing to 1/	
Change in labor supply of females	25.4
Change in computer investment	-17.2
Change in durables employment	-4.9
Change in the real exchange rate	-1.6
Residual	2.7

The negative relationship between computer investment and the standard deviation of industry wages suggests that computer investment reduces the standard deviation of wages by raising productivity and wages in low wage sectors more than in high wage sectors. As low-wage sectors tend to be services, which use little heavy capital equipment, computer and communications investment will represent a higher proportion of total investment than in other sectors and will likely make a larger contribution to total productivity growth in these sectors than in sectors intensive in other forms of capital.

A panel regression of the average rate of office equipment (computers, photocopiers, etc.) and communications investment growth over 1970-92 on the 1970 wage premium in the 38 two-digit sectors reveals that high-tech investment has grown more rapidly in low wage sectors (see tabulation below). This result suggests that high-tech investment may have caused a

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1/ Difference between the wage differential obtained by holding the particular explanatory variables constant at their average level in the 1970s and the wage differential in 1990.

greater productivity and wage gain in low-wage sectors than high-wage sectors, which would explain why equipment investment corresponds to a narrowing of the standard deviation of wages. The wage premium earns a negative coefficient of -0.720, significant at the 1 percent level; the initial premium explains 51 percent of cross-sectional variation in investment growth rates. To prevent small sectors from skewing the aggregate relationship in the regression, each sector is weighted by its average employment share.

Relationship Between High-Tech Investment and Industry Wage Premia

Dependent variable: Change in real office equipment and communications investment, 1970-92 1/

	Employment-Weighted	GDP-Weighted
Wage premium 1970 (percent)	-0.720	-0.493
	(-7.10)	(-3.16)
Adjusted R^2	0.513	0.160

If instead observations are weighted based on sectoral GDP, a negative relationship between initial wages and high-tech investment growth is again found, albeit with a smaller coefficient (-0.493 versus -0.720) on investment and weaker fit. While GDP weighting is a more common approach in cross-industry studies, this approach can distort the results by giving excessive weight to sectors such as real estate or finance which generate very high income but employ few people.

VII. Conclusion

This paper finds that changes in employment in durable manufacturing industries and investment in computer equipment can explain rising wage dispersion in the United States, measured in terms of the education premium. This finding represents a refinement of the Borjas and Ramey hypothesis that the trade deficit in durable goods explains changes in the education differential. Reduced employment opportunities in durables production drive down the average wage of workers with only high school education, thereby forcing up the premium for college education. An innovation in this paper is the inclusion of investment in equipment as a proxy for skill-biased technical change rather than it as a residual or with a time trend. The rise in the skill premium associated with the use of technology could alone explain all of the rise in the college premium since 1979 were there no offsetting effects. The real effective exchange rate also helps to explain

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1/ A constant term was included in each equation, although its estimate is not shown.

the rise in the education differential in the short run by altering the competitiveness of the U.S. durable goods industry and thus affecting the industry's optimal size and employment.

This paper also finds that the major factor behind the rise in wage inequality across industries is the rise in the female labor force participation rate. This rise more than offsets the effect of the decline in durable employment, and the rise in computer investment and the real exchange rate, all of which reduce interindustry wage inequality.

Definitions of Variables Used in Empirical Analysis

All variables are annual time series and are natural logarithms unless stated otherwise.

College-high school education differential (w_{hs}):

The ratio of the average weekly earnings for male college graduates and high school graduates aged 18-64 who worked full-time, year-round in the year prior to the survey and were not self-employed or unpaid. Average weekly earnings are calculated from the annual demographic files of the Current Population Survey 1971 to 1991 (reflecting earnings in 1970-1990), are adjusted for experience, and are converted to 1982 dollars using the GNP implicit price deflator for personal consumption. Supplied by George Borjas and Valerie Ramey; see Borjas and Ramey (1994b) for further details on calculation.

College-dropout education differential (w_{dp}):

Defined as above using Current Population Survey data for college graduates and for workers who did not complete high school.

Standard deviation of industry wages (σ_{ind}):

The standard deviation of two-digit industry compensation relative to employment-weighted average real compensation. Compensation data includes wages and benefits paid to full-time equivalent employees (from the National Income and Product Accounts, Bureau of Economic Analysis, as supplied by Haver Analytics) and is adjusted for inflation using the urban CPI (Bureau of Labor Statistics, as supplied by Haver Analytics). The two-digit industries analyzed are in the manufacturing, transportation and communication, wholesale and retail trade, and private service sectors.

Industry wage premium:

The 1970 wage premium in industry *i* for 38 two-digit sectors relative to the average wage. The average wage is calculated with either employment weights or GDP weights. Wage data is the same as above, industry GDP data is from the National Income and Product Accounts, Bureau of Economic Analysis, as supplied by Haver Analytics.

Employment in durable goods production (demp):

The ratio of production and nonproduction employment in durable goods industries to aggregate employment, where both refer to full-time equivalent employees. Durable good sectors include lumber and wood products; furniture and fixtures; stone, clay, and glass products; primary metal industries; fabricated metal products; industrial machinery and equipment; electronic and other electric equipment; motor vehicles and equipment; other transportation equipment; instruments and related products; and other miscellaneous manufacturing. Establishment survey data from the Bureau of Labor Statistics as supplied by Haver Analytics.

Real investment in computerized equipment (compi):

Investment in office, computing, accounting and communication equipment in 1987 dollars by two-digit sector. Aggregated from Detailed Investment by Industry, National Income and Product Accounts, Bureau of Economic Analysis.

College-educated population (cgrad):

The percentage of college graduates among persons age 25 or older, from the Current Population Survey, Bureau of the Census.

Trade deficit in durable goods (ddef):

Calculated as a percentage of GDP, both in real terms, where net imports are positive. In levels (not logarithms). From Citibase.

Female labor force (flf):

The supply of women age 20 or over in the labor force as a share of the aggregate labor force. Household survey data from the Bureau of Labor Statistics, as supplied by Haver Analytics.

Real effective exchange rate (reer):

J.P. Morgan index of the U.S. dollar real effective exchange rate versus 22 OECD and 23 LDC currencies, 1990=100, as supplied by Haver Analytics. An increase reflects appreciation.

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Table 1. Phillips-Perron Tests for Stationarity of Time Series Data

Phillips-Perron tests include a constant and a time trend. The Z_ρ and Z_t statistics are shown; if the Z_ρ and Z_t statistics exceed their respective *x* percent critical values, then we reject the null hypothesis that the series is I(1) with *1-x* percent probability.

Series	$Z\rho$	Z_t
w_{hs}	0.28	0.16
w_{dp}	0.61	0.44
σ_{ind}	-1.40	-2.49
Durables employment	0.24	0.22
College graduates	-1.40	-5.13*
Female labor force	-0.32	-0.82
Computer investment	0.15	0.22
Real effective ER	-7.71	-2.08
Durables deficit	-3.50	-1.36

* Denotes that the null hypothesis of a unit root can be rejected at the 5 percent level ($Z_\rho < -17.9$, $Z_t < -3.6$).

Table 2. Johansen Maximum Likelihood Tests and Parameter Estimates of the Determinants of the College Graduate-High School Graduate Differential

A. Cointegration likelihood ratio test based on maximal eigenvalue of the stochastic matrix

Hypothesis			
Null	Alternative	Test Statistic	95 Percent Critical Value
r = 0	r = 1	70.2	33.32
r ≤ 1	r = 2	54.0	27.14
r ≤ 2	r = 3	22.3	21.07
r ≤ 3	r = 4	9.5	14.90
r ≤ 4	r = 5	1.5	8.18

B. Cointegration likelihood ratio test based on trace of the stochastic matrix

Null	Alternative	Test Statistic	95 Percent Critical Value
r = 0	r ≥ 1	157.5	70.60
r ≤ 1	r ≥ 2	87.3	48.30
r ≤ 2	r ≥ 3	33.3	31.50
r ≤ 3	r ≥ 4	11.0	17.95
r ≤ 4	r ≥ 5	1.5	8.18

C. Estimated cointegrating vector

w_{hs}	cgrad	compi	demp	reer
-1	-0.51	0.10	-0.69	0.07

Table 3. Estimated Determinants of the College Graduate-High School Graduate (w_{hs}) and College Graduate-High School Dropout (w_{dp}) Differentials (all variables in logarithms)

Ind. variable 1/	w_{hs} Long-Run	w_{hs} Short-Run 2/	w_{dp} Long-Run	w_{dp} Short-Run 2/
Durables employment	-0.69		-0.79	
College graduates	-0.51		-0.59	
Computer investment	0.10		0.14	
Real effective ER	0.07		0.08	
Δ(Durables emp)		-0.38 (4.10)		-0.49 (3.98)
Δ(College graduates)		-0.25 (2.11)		-0.48 (3.08)
Δ(Computer investment)		0.11 (2.88)		0.21 (3.90)
Δ(Real effective ER)		0.09 (2.61)		0.14 (3.06)
Long-run error		-0.64 (-4.44)		-0.71 (4.20)
Durbin-Watson		2.74		2.40
Adjusted R^2		0.72		0.67

1/ A constant term is included in all equations, although its estimate is not shown.

Table 4. Johansen Maximum Likelihood Tests and Parameter Estimates of the Determinants of the College Graduate-High School Dropout Differential

A. Cointegration likelihood ratio test based on maximal eigenvalue of the stochastic matrix

Hypothesis			
Null	Alternative	Test Statistic	95 Percent Critical Value
r=0	r=1	78.6	33.32
r≤1	r=2	33.4	27.14
r≤2	r=3	26.3	21.07
r≤3	r=4	12.0	14.90
r≤4	r=5	1.8	8.18

B. Cointegration likelihood ratio test based on trace of the stochastic matrix

Null	Alternative	Test Statistic	95 Percent Critical Value
r=0	r≥1	152.1	70.60
r≤1	r≥2	73.5	48.30
r≤2	r≥3	40.1	31.50
r≤3	r≥4	13.8	17.95
r≤4	r≥5	1.8	8.18

C. Estimated cointegrating vector

w_{dp}	cgrad	compi	demp	reer
-1	-0.59	0.14	-0.79	0.08

Table 5. Johansen Maximum Likelihood Tests and Parameter Estimates of the Determinants of the Standard Deviation of Industry Wages

A. Cointegration likelihood ratio test based on maximal eigenvalue of the stochastic matrix

Hypothesis			
Null	Alternative	Test Statistic	95 Percent Critical Value
r=0	r=1	47.4	33.32
r≤1	r=2	31.1	27.14
r≤2	r=3	20.9	21.07
r≤3	r=4	9.0	14.90
r≤4	r=5	0.0	8.18

B. Cointegration likelihood ratio test based on trace of the stochastic matrix

Null	Alternative	Test Statistic	95 Percent Critical Value
r=0	r≥1	108.3	70.60
r≤1	r≥2	61.0	48.30
r≤2	r≥3	29.9	31.50
r≤3	r≥4	9.0	17.95
r≤4	r≥5	0.0	8.18

C. Estimated cointegrating vector

σ_{ind}	flf	compi	demp	reer
-1	1.78	-0.12	0.16	-0.06

Table 6. Estimated Determinants of the Standard Deviation of Industry Wages, σ_{ind} (all variables in logarithms)

Ind. Variable 1/	Long-Run Equation	Short-Run Equation 2/
Durables employment	.16	
Female labor force	1.78	
Computer investment	-0.12	
Real effective ER	-0.06	
Δ(Durable employment)		-0.07 (2.10)
Δ(Female labor force)		0.20 (0.81)
Δ(Computer investment)		-0.01 (0.83)
Δ(Real effective ER)		-0.01 (0.53)
Long-run error		-0.28 (2.19)
Durbin-Watson		1.67
Adjusted R^2		0.47

1/ A constant term is included in all equations, although its estimate is not shown.
2/ t-statistics appear in parentheses.