RELATIVE EARNINGS OF SKILLED AND UNSKILLED WORKERS: EXPLAINING INCREASING EARNINGS OF COLLEGE GRADUATES AS THEIR SHARE OF THE LABOR FORCE GROWS

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I. THE ISSUE

We sometimes need to project average earnings for specified levels of education, for example to project lost future earnings for a child not yet in the labor force when injured.

Earnings for different levels of education have not all grown at the same rate. One could simply project the future rate of increase for any particular level of education based on the past, but if the changes in the past were not consistent with economic theory, or if the past changes represented adjustment to one-time external shifts, we could be criticized for not understanding what we are doing, or why.

The questions addressed by this paper are two: First, can economic theory reconcile the changing composition of the work force with the changing earnings for different levels of education? (Answer: yes). Second, is it plausible to project those changes into the future? (Answer: that is your call, but I think so – at a lower rate than in the past).

II. STYLIZED FACTS

I consider the difference between earnings of those with a four-year college degree or better (skilled workers) and those with less education (unskilled workers). The average level of education of the labor force has been increasing, and the earnings of those with four years or more of college have been increasing relative to those with less.

Data going back to 1974[1] shows the facts summarized in Table 1, below. The gap between growth rates of real earnings for skilled and unskilled males is approximately 1% and for females it is 0.7%, despite the fact that the skilled numbers grew much faster than unskilled.[2]

To fit these facts into standard economic theory I use the simplest possible macro model with three factors of production: skilled and unskilled labor, plus capital.

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[1] I use 1974 as the first year because the Census Bureau provides convenient historical compilations from the PINC tables showing educational attainment and earnings for people 18 years old and older. However the process had started by the early 1960s. See He and Liu (2007).

[2] Real earnings in Table 1 are calculated using two alternative measures of inflation: The GDP Implicit Price Deflator, BEA series B191RG3, and the Consumer Price Index – All Urban Consumers (1982 – 84 = 100, BLS series CUUR0000SA0. Note the differences in real income growth rates depending on the price series used.

TABLE 1. GROWTH IN FULL-TIME SKILLED AND UNSKILLED WORKERS AND THEIR AVERAGE REAL EARNINGS, 1974 – 2009

	Male trend growth rate	Male trend growth, 35 yrs	Female trend growth rate	Female trend growth, 35 yrs
Growth in number of unskilled workers (< 4 years college)	1.1%	46%	2.0%	103%
Growth in average real earnings, unskilled (GDP IPD)	0.4%	17%	1.2%	52%
Growth in average real earnings, unskilled (CPI-U)	-0.2%	-7%	0.6%	22%
Growth in number of skilled workers (≥ 4 years college)	2.7%	153%	5.0%	467%
Growth in average real earnings, skilled (GDP IPD)	1.4%	62%	1.9%	94%
Growth in average real earnings, skilled (CPI-U)	0.7%	29%	1.3%	55%

To measure the quantity of skilled and unskilled labor is not straightforward. Other features of the labor force besides the ratio of skilled to unskilled workers have also changed dramatically: the ratio of female to male, of full-time to part-time, and of old to young workers have all increased; and the relative pay of female to male and old to young workers have increased over time.

Therefore I have used an artificial construct of the labor force, the number of “mature male full-time equivalent” (MMFTE) workers, calculated by dividing *the total wage bill for unskilled workers* by *the average full-time wage for male high school graduates aged 45 to 55*, and dividing *the total wage bill for skilled workers* by *the average full-time wage for male four-year college graduates aged 45 to 55*. This means that workers earning less than the standard in each category are recorded as less than one mature male full-time equivalent, and those earning more than the standard are recorded as more than one mature male full-time equivalent. These differences in MMFTE equivalents are due to differences in education (within the unskilled or skilled general category), to age, to sex, and to part-time *vs.* full-time status.

Standard theory says that high wages in late middle age arise from human capital created by experience. If we are exploring the growing return to formal education over time, we should attempt to isolate it from the growing return to experience, as the MMFTE measure does.

Using these constructs, Table 1 is transformed as shown in Table 2. Table 2 drops use of the CPI-U measure of inflation, to focus on the GDP Implicit Price Deflator from the National Income and Product Accounts; the reason for this focus is explained below, in section IV.1.

TABLE 2. GROWTH IN MATURE FULL-TIME EQUIVALENT WORKERS AND FULL TIME REAL EARNINGS, 1974 – 2009, BASED ON GDP IMPLICIT PRICE DEFLATOR

	Trend growth rate	Trend growth, 35 yrs
Growth in number of MMFTE unskilled workers (< 4 years college)	1.6%	77%
Growth in average real earnings, male high school graduates aged 45 - 55	0.1%	4%
Growth in number of MMFTE skilled workers (≥ 4 years college)	3.9%	292%
Growth in average real earnings, male college graduates aged 45 - 55	0.8%	31%

Charts 1 and 2 show the annual changes, with trends. I have tried different measures for full-time equivalent workers, and for average earnings; they show the same general story.

III. MODEL

What determines real wage increases?

Standard economic theory says that in a competitive labor market, the wage rate is equal to marginal revenue product (marginal revenue $\times$marginal physical product), or in symbols:

(1) $$W = MR \times MPP$$

where MPP is the partial derivative of the production function with respect to the quantity of (the particular class of) labor. We must assume that MPP is declining as the amount of the factor increases, for (1) to define a profit maximum rather than a minimum.

What actions make sure that equation (1) holds? The employer is the decision maker, and faces a wage beyond his control. If the output market is also competitive, marginal revenue equals price (P), and is also beyond the employer's control. What is in his control is the amount of each input that he hires, so he expands or contracts inputs, adjusting factor proportions and possibly total output to change MPP, so as to change the right hand side until it equals W.[1] Equation (1) describes a relationship toward which the employer is adjusting over time, with the time frame dependent on how quickly it is economical to adjust the particular factor of production. In fact, (1) is only an approximation made by fitting a complex dynamic process with adjustment costs into a static equilibrium strait jacket.

I specialize the theory to a Cobb-Douglas constant returns to scale production function intended to represent the economy's aggregate production function with competition in both input and output markets, with technical change, using unskilled labor L_u, skilled labor L_s, and capital K to produce real output, y (output in current dollars, Y, divided by a price index, P).[2]

(2) $$y \equiv Y/P = e^{gt} \cdot L_u^a L_s^b K^c, \quad a+b+c=1.$$

The growth rate g, intended to represent the annual rate of technical progress, might be disembodied as written in (2) or embodied in increasing productivity of any of the individual factors, for example skilled labor. In the latter case we would have "effective units" of skilled labor growing at the rate g/b per capita each period. However, in the particular case of a Cobb-Douglas function the technical progress is apportioned among all three of the factors of production in the form of wage increases, whether embodied or disembodied.

Where nominal wages for unskilled and skilled labor and capital are represented by W_u, W_s, W_k and real wages are represented by lower case letters, $w_i \equiv W_i/P, \quad i=u,s,k,$ we have from (2):

(3) $$w_u = \partial y/\partial L_u = ay/L_u; \quad w_s = \partial y/\partial L_s = by/L_s; \quad w_k = \partial y/\partial K = cy/K.$$

Writing the wages in this way makes two things clear. First, the marginal physical product of each input is a constant fraction of the average product of that input. Second, (3) exhibits the adding up property, total wage payments to the three factors of production exhaust the total product:

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[1] By measuring the number of workers as mature male full-time equivalents, I am assuming that the employer perceives each worker's marginal productivity as proportional to that worker's earnings: younger workers are less productive, those with less education are less productive, women are less productive (presumably because on the average they choose less productive work), and part-time workers are less productive than the standard full time male worker aged 45 – 55, with a high school or 4-year college degree.

[2] For a two-factor version of the single sector production function, Solow (1957, p. 318) makes the point that it is virtually impossible to distinguish among alternative functional forms in fitting data to inputs and outputs; the Cobb-Douglas form is simpler than others, and convenient to manipulate.

(4) $$w_u \cdot L_u + w_s \cdot L_s + w_k \cdot K = (a+b+c)\cdot y = y.$$

Changes over time

Assume that all variables in (2) and (3) vary over time, and calculate the percentage rate of change in the skilled wage. If the coefficients *a, b,* and *c* are constant, where dotted variables represent time derivatives, taking the logarithmic derivative[1] of (3b) with respect to time we have:

(5) $$\underbrace{\frac{\dot{w}_s}{w_s}}_{\text{\% incr., skilled wage}} = \underbrace{g}_{\substack{\text{rate of tech.}\\ \text{change}}} - \underbrace{a\cdot\left(\frac{\dot{L}_s}{L_s}-\frac{\dot{L}_u}{L_u}\right)}_{a\cdot\text{\% incr., (skilled/unskilled) labor}} - \underbrace{c\cdot\left(\frac{\dot{L}_s}{L_s}-\frac{\dot{K}}{K}\right)}_{c\cdot\text{\% incr., (skilled labor/capital)}}$$

The first term on the right-hand side of (5) show that technical change will directly produce an equal percentage change in the wage rate for skilled labor (and for each of the other factors). The last two terms show that any other change in the wage rate for skilled labor is a function of the growth rate of its quantity relative to the other two factors. In particular, if skilled labor grows faster than unskilled labor, the wage for skilled labor *falls*: relative abundance lowers the relative wage. The last term in (5) could offset that effect, if capital grew even faster than skilled labor; but in that case the wage for unskilled labor would grow even faster than the rate for skilled labor, which has not been the case.

Equation (5) is not consistent with the stylized facts reported above: the real wage rate for skilled labor has grown even while the amount of skilled labor has grown relative to unskilled labor, and wages for unskilled labor have barely kept ahead of inflation. The only way to explain these facts within the model of equation (2) is to assume that the coefficients *a, b, c* are also changing over time.

It would lead to many other difficulties of modeling to assume that the sum $a+b+c$ could exceed one (we could not then have existence of competitive equilibrium) so the natural assumption is that $\dot{a}+\dot{b}+\dot{c}=0$. It is generally thought that the capital share has remained stable over a long period, implying that *c* is roughly constant; see (Thomas F. Cooley and Edward C. Prescott, 1995 pp. 11, 20), but it is not necessary to restrict *c* in that way. I shall instead measure *c* as $1-a-b$, with $\dot{c}=-(\dot{a}+\dot{b})$. With these assumptions, (5) is expanded as follows:

(6) $$\frac{\dot{w}_s}{w_s} = \left[g - a\cdot\left(\frac{\dot{L}_s}{L_s}-\frac{\dot{L}_u}{L_u}\right) - c\cdot\left(\frac{\dot{L}_s}{L_s}-\frac{\dot{K}}{K}\right)\right] + \frac{\dot{b}}{b} + \left\{\dot{a}\cdot\ln L_u + \dot{b}\cdot\ln L_s + \dot{c}\cdot\ln K\right\}.$$

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[1] The logarithmic derivative is the derivative with respect to time of the equation $\ln w_s = \ln(by/L_s)$.

In (6), the term in square brackets is the right-hand side of (5).

The comparable expression for the percentage change in the unskilled wage is

$$(7)\ \frac{\dot{w}_u}{w_u} = \left[g + b \cdot \left(\frac{\dot{L}_s}{L_s} - \frac{\dot{L}_u}{L_u} \right) - c \cdot \left(\frac{\dot{L}_u}{L_u} - \frac{\dot{K}}{K} \right) \right] + \frac{\dot{a}}{a} + \left\{ \dot{a} \cdot \ln L_u + \dot{b} \cdot \ln L_s + \dot{c} \cdot \ln K \right\}.$$

Notice that the terms in curly brackets are identical in equations (6) and (7). Changes over time in the coefficients *a* and *b* have their impact through the middle terms in equations (6) and (7): $\dot{b}/b$ in (6) and $\dot{a}/a$ in (7).

In fact, the trend percentage rate of change in *a* is -1.3% per year, while the trend percentage rate of change of b is +1.6%, so the assumption that coefficients of the production function change over time does provide a possible explanation of the puzzle.

Equation (6) could be used to show how the observed increase in skilled wages is decomposed into its constituent parts. A somewhat simpler, but equivalent, equation comes from (3) without decomposing $\dot{y}/y$ into its constituent parts:

$$(8)\qquad \ln(w_s) = \ln(b) + \ln(y) - \ln(L_s)$$

Differentiating (8) and the comparable expression for unskilled labor with respect to time,

$$(9)\qquad \dot{w}_u/w_u = \dot{a}/a + \dot{y}/y - \dot{L}_u/L_u; \quad \dot{w}_s/w_s = \dot{b}/b + \dot{y}/y - \dot{L}_s/L_s\ .$$

Section V, below, shows the trend values for these variables and gives an account of what causes the increase in skilled relative to unskilled wages. To show that the right-hand side of (9a) or (9b) is equal to the left-hand side is not a statistical test, though, because *a* and *b* are calculated to make equation (3), and therefore (8) true, year by year. Using annual rates of change in the underlying variables of (3) to estimate (9) introduces tiny errors – never more than a few hundredths of 1% for any year. Substituting trend values for actual values gives comparable errors, but (9) fitted to trend values is simply an accounting device to show why the wages moved as they did; and it confirms that the assumptions about the changes over time in *a, b,* and *c* are approximately true.

Note that I do not address the supply of labor: labor force participation rates, unemployment rates, the division of the labor force into skilled and unskilled workers, and into full-time and part-time workers within each group, are treated as exogenous.

IV. DATA

The data on earnings by education comes from the country's largest survey of earnings by education, and the survey with the longest time series: the U.S. Census Bureau's Current Population Survey (CPS), Annual Social and Economic Supplements (formerly known as the March supplement, but now collected in part in February and April).

The CPS has sampling errors and non-sampling errors; all of the reasons for error other than the ego of the respondent suggest that the estimates are understated.[1] Nevertheless, aggregated over all levels of education these earnings exceed wages and salaries reported in the national income accounts.[2] See Chart 3.

Following is a discussion of the variables used in equations (6) and (7). Detailed references are in the data appendix, available from the author.

1. **The rate of growth of real earnings for unskilled and skilled workers,** $\dot{w}_u/w_u$, $\dot{w}_s/w_s$.

Historical tables from the CPS provide numbers of workers and earnings from 1974 to 2009 for several education classes, by age group, both for all workers and for full-time year-round workers, with figures reported separately for males and females. The population from which the sample is drawn is the non-institutional population, and excludes military personnel unless living with a civilian. Annual earnings are reported in current dollars and dollars of 2009 purchasing power, with the latter calculated using the Consumers' Price Index for all urban consumers. The education classes used changed in 1991; before that, those with less than 4 years of college were divided into 4 groups, and those with 4 years or more were divided into 2 groups. Starting in 1991, those with less than a bachelor's degree were divided into 5 groups, and those with a bachelor's degree or more were divided into 4 groups. The division into unskilled and skilled labor used here is the

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[1] The earnings in question are pretax earnings; the survey was originally taken in March in the hope that respondents would then be compiling records for their tax returns and would know their pretax earnings. Total *income* in the survey is notoriously understated but earnings are thought to be fairly accurate (see DeNavas-Walt *et al.*, 2007). The potential reasons for understatement of earnings are lack of knowledge of the respondent's own pre-tax earnings or those of other members of the household (especially when the surveyor settles for information from a teenaged child after lack of success in contacting an adult), concealment of illegal earnings, or concealment of some income items from other family members. For a general overview of errors in the CPS see Weinberg (2004) and DeNavas-Walt *et al.* (2007, Appendix A, p. 27).

From my forensic experience, people asked for their earnings, even if they have W-2 forms in front of them, respond with taxable wages, neglecting the tax-favored earnings that are included in Medicare wages. It seems likely that the same phenomenon occurs in the CPS.

[2] See U.S. Bureau of Economic Analysis, Integrated Macroeconomic Accounts for the U.S., Table S.1. Total Economy - Current Account, line 14: Wages and Salaries.

division between less than 4 years of college and 4 years or more, to 1990, and between those with less than a bachelor's degree, and those with a bachelor's degree or more, from 1991 on.

The measure of MMFTE workers implicitly weights workers of different wages differently according to their earnings, so workers of different ages have different weights. The macroeconomic analysis of this paper does not include separate calculations for different age groups; figures reported are for all workers, 18 years old and over.[1]

I used real earnings in 2009 dollars, but used a price index for GDP rather than the CPI-U used by the Census Bureau.[2] The reason for this choice is that the economic theory of Section IV links the cost of hiring a worker to that worker's marginal product; the employer cares about what he can sell the product for, not what the employee can buy with it. Changes in the marginal product should be tracked by a price index for output.[3]

To combine male and female, old and young, full-time and part-time workers of different education levels within each skill group, as explained above I calculated a series for "mature male full-time equivalent" (MMFTE) workers by dividing the total earnings of all workers in a given skill class (unskilled or skilled) by the earnings of male full-time workers aged 45 – 55: high school graduates for the unskilled, and 4-year college graduates for the skilled.

The wage growth rate $\dot{w}_i/w_i$ is the annual percentage rate of increase in w_i ($i = u, s$). For most purposes this is calculated as the average annual percentage rate of increase, r, from the least squares exponential trend

$$\hat{w}_i = k \cdot (1 + r)^t, \qquad (9)$$

where the hat over w_i represents the estimated value, and t is the year (t = 1974, 1975, …, 2009). Taking the logarithmic derivative gives

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[1] The spread between pay for older and younger workers increased by 14% between 1980 and 1990 (Aghion *et al*, 1999); this fact prompted use of the MMFTE measure for number of workers.

[2] The price index used is the Implicit Price Deflator for GDP published by the Bureau of Economic Analysis in National Income and Product Table 1.1.9 (series B191RG3), 2005 = 100, scaled to 2009 = 100.

[3] We really should use employees' compensation, including fringe benefits and mandated employer costs, rather than wages. We know a lot about employer's cost classified by industry and by occupational groups, but to the best of my knowledge there is no information on how employer's cost varies by the average educational level of the employee, so that correction is not available. However for all workers combined, compensation has grown faster than wages; it seems likely that this would have increased relative compensation for skilled workers at an even faster rate than is shown by the wage series.

(10) $$\frac{d(\hat{w}_i)/dt}{\hat{w}_i} = \ln(1+r).$$

For annual rates of change to approximate the time derivative expressed as a percent of the wage, the approximation used is:

(11) $$\dot{w}_i/w_i \approx 2\cdot\left[w_i(t+1)-w_i(t)\right]/\left[w_i(t+1)+w_i(t)\right].$$

This expresses the change from t to $t+1$ as a percentage of the average level of $w_i(t)$ and $w_i(t+1)$. This same approximation is used for other percentage rates of change when the calculations are required year-by-year.

2. The rate of growth of unskilled and skilled labor's share of output, $\dot{a}/a$, $\dot{b}/b$.

The share of each class of labor, *a* and *b*, is calculated year by year from equation (3). The average percentage rates of increase, $\dot{a}/a$ and $\dot{b}/b$, are then calculated as the average rates of increase in the least squares exponential trends $\hat{a} = k\cdot(1+r)^t$ and $\hat{b} = k\cdot(1+r)^t$, as in section V.1, above.

3. The rate of growth of real output, $\dot{y}/y$.

Real output, *y*, is set equal to Gross Domestic Product from the Bureau of Economic Analysis' National Income and Product Accounts. The series as recorded is in current dollars, converted to constant dollars using the same price index as used for wages.

The percentage annual rate of increase, $\dot{y}/y$, is then calculated as the average rate of increase in the least squares exponential trend $\hat{y} = k\cdot(1+r)^t$, as in section V.1, above. Even though the labor series used excludes some military personnel, it seems more appropriate to include government in the measure of output than to exclude it.

4. The rate of growth of unskilled and skilled labor, $\dot{L}_u/L_u$, $\dot{L}_s/L_s$.

The quantity of each kind of labor is calculated year by year as described in section V.1, above. The percentage annual rate of increase, $\dot{L}_u/L_u$ or $\dot{L}_s/L_s$, is then calculated as the average rates of increase in the least squares exponential trends $\hat{L}_i = k\cdot(1+r)^t$ ($i = u, s$), as in section V.1, above.

5. The rate of growth of capital, $\dot{K}/K$.

The capital stock is taken from the NIPA Fixed Asset Table 1.1, Current Cost Net Stock of Fixed Assets and Consumer Durables [Billions of dollars; year end estimates).[1] Output and earnings are recorded for calendar years, which implies that the MMFTE labor force is also estimated for calendar years; for consistency the geometric average of the beginning and end of year capital stocks is used to approximate the midyear value. The series used is line 2 of the table, measuring private plus government fixed assets (but excluding consumer durable goods other than housing, since the output of those goods is not included in GDP). The nominal capital stock is converted to real values using the same GDP implicit price deflator as is used for other series in this paper. The percentage annual rate of increase is calculated as for the other variables.

V. EMPIRICAL RELATIONSHIPS

The changes in *a* and *b* over time are shown in Chart 5; the chart also shows that the trend value of *a* + *b* (and therefore of *c*) is approximately constant. Equations (9a) and (9b) yield the following results based on trend lines:

TABLE 3. ANNUAL TREND CHANGES IN WAGES AND THEIR DETERMINANTS, 1974 - 2009

Unskilled labor	$\dot{a}/a$	$\dot{y}/y$	$\dot{L}_u/L_u$	$\frac{\dot{a}}{a}+\frac{\dot{y}}{y}-\frac{\dot{L}_u}{L_u}$ [(9) RHS]	$\dot{w}_u/w_u$ [(9) LHS]
	-1.29%	3.03%	1.65%	**0.09%**	**0.11%**
Skilled labor	$\dot{b}/b$	$\dot{y}/y$	$\dot{L}_s/L_s$	$\frac{\dot{b}}{b}+\frac{\dot{y}}{y}-\frac{\dot{L}_s}{L_s}$ [(9) RHS]	$\dot{w}_s/w_s$ [(9) LHS]
	1.64%	3.03%	3.91%	**0.76%**	**0.77%**

Unsurprisingly, the left-hand side of equations (9a) and (9b) shown in the last column of Table 3, are approximately equal to the right-hand side shown in the adjacent column. When calculated year by year, rather than using trend values,

[1] http://www.bea.gov/National/FA2004/SelectTable.asp#S1

despite erratic movements in the annual data, the agreement between the right-hand and left-hand sides of (9) is equally close.[1]

VI. DISCUSSION

For the forensic economist thinking about the need to project relative wages into the future, the important question is whether the rates of change of the past 35 years will continue into the future; to answer that question we need to know what caused the past changes.

Six suggestions come from the labor economics literature, based on other important changes that have been taking place over the same period (Goldin & Katz, 2009). First, world trade has expanded, with many low-wage jobs being shipped overseas. In a two-country model with trade in final goods, such changes lead to a rise in the relative wages of skilled labor in the rich country, and a fall in the poor country. In a more complex model with trade in intermediate goods, if unskilled labor is more of a substitute for intermediate goods than is skilled labor, the effect is intensified. (Aghion *et al.*, 1999, p. 1635 ff.) However, the shifts in commodity prices that are needed for this transmission mechanism have not been big enough to explain very much of the increase in earnings of skilled labor. The research is reviewed by Meckl and Weigert (2003, p. 320). Moreover other predictions of the theory have not been supported by empirical work: all industries should move toward use of more skilled labor together; and the premium for skilled labor should fall in developing countries. Meckl & Weigert and others propose more elaborate theories to get more mileage from the expansion of trade, but as a recent paper states, the general consensus is that the alternative discussed below provides a more compelling story (He and Liu, 2008, p. 316 n. 1; Skaksen and Sorensen, 2005). For my current purposes, I will point out that these trade-based models, if valid, lead to a one-time increase in relative numbers and relative wages for skilled labor based on a one-time expansion of trade opportunities: continuation of the trend into the future would require a succession of new stimuli to world trade, through lowering of transport costs or other mechanisms.

The second mechanism generating higher rewards to education is the spread of computing, considered to be a general purpose technology, or more generally skill-biased technical change (SBTC), interpreted as a combination of complementarity between capital equipment and skilled labor, combined with rapid growth in capital equipment (see Skaksen & Sorensen, 2005, p. 1). Both directly and

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[1] Year by year values of the variables for both the RHS and the LHS of equation (8) are calculated by formulas similar to that shown in equation (9). There are some small errors in the fourth decimal place, due to the annual approximations to instantaneous rates of change.

indirectly through induced organizational change, several models suggest that this relationship is plausible (Aghion *et al*., 1999, p. 1635 ff.).

Krusell et al. (2000) and He and Liu (2008) provide rich models that add good empirical support for the theory. The models require a more elaborate production function than the Cobb-Douglas form used above, so as to distinguish between equipment and structures in the capital stock, and to permit complementarity between skilled labor and equipment. Krusell *et al.* build a model that treats the skill-biased technical change and the mix of skilled and unskilled labor as exogenous; they explore how the relative wages will respond over time.[1] He and Liu are more ambitious, making the choice of investment in human capital respond endogenously to the rise in returns to education, aspiring to explain both the change in the supply of skilled labor and its wage as an equilibrium outcome responding to the exogenous technological change. Both do well at explaining the past path of relative earnings based on the long-run skill-biased technical change.

Other possible causes for the trend have been proposed. "Greater immigration of low-wage workers, the decline in private-sector unionization, the erosion of the real value of the federal minimum wage, and changes in social norms concerning the pay of executives and other top-end earners" (Goldin & Katz 2009, p. 90). None of these alone could explain the scope of the changes that have occurred, as can SBTC. SBTC becomes a particularly compelling explanation when coupled with analysis of the supply shifts that have occurred first when the returns to education were falling in the first half of the 20th century then rising since the 1970s (Goldin & Katz 2009, Chapter 8).

From the perspective of a forensic economist hoping to apply the insights of these models to project future earnings of today's or tomorrow's high school and college graduates, we need to consider whether we believe that the information revolution stemming from the increased use of computing is continuing or is essentially finished. I think that the revolution still has a considerable distance to go. The simple Cobb-Douglas model of Section IV provides some insight that is less optimistic.

Equation (2) can be turned into an equation to estimate annual values of g, the rate of technical change, given the other variables. The trend from the result of that exercise is a value of g that starts at 1.36% in 1974 and declines to -0.10% by 2006.These trend values conceal a lot of annual turmoil, however. Chart 6 shows

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[1] Krusell *et al.* use a somewhat idiosyncratic price series for capital equipment, intended to respond to criticism that the standard price series in the National Income and Product Accounts failed to correct for important technical improvements in quality. Polgreen and Silos (2008) have recalibrated the model using newly revised price series from NIPA to get results that are somewhat different from those of Krusell *et al.* but supportive of their claims.

the calculation of annual values of g from equation (2). I also note that Chart 5 shows a flattening out in the share of income going to skilled workers in the past eight years.

VII. FROM MACRO TO MICRO

My formulation of the growth in the labor force and in wage rates may be useful for the macroeconomic question of isolating the effect of technical change; but it does not help to project earnings growth for someone other than a mature male high school or college graduate. We know that much of the increase in earnings came from changes in labor supply – people moving from part- to full-time jobs, and from lower levels of education to higher, within as well as between the two classes of labor that I have used. In addition, we know that women's wages have grown faster than men's. So while the fact that earnings for college graduates seems to be explained by SBTC is useful, and the fact that technical change might be slowing down should be kept in mind, neither of those facts tells us how to project earnings for (e.g.) a woman with 1 to 3 years of college, or an associate's degree. For that we need more detailed projections.

Unfortunately, when divided into the smallest possible cells (by sex, education, and age) trends are not as clear as for larger groupings. Table 4 shows the trend rates of growth of numbers and of average incomes for full-time, year-round workers, together with values of R^2 as a rough measure of goodness of fit; the rates of income growth with $R^2 \geq 0.5$ are in bold type.[1] Table 4 combines the group definitions for the period 1974 – 1990 with comparable groups for 1991 – 2009, as indicated in the section headings.[2]

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[1] Values of R^2 are shown to just two places in the table but values rounded up to 0.50 from below are not shown in boldface. I have computed trends for some combinations of education, sex and age for which values are not reported for all years in the BLS data. The missing data were filled in by using arithmetic: First, for each level of education, sex and year the average income of workers of all ages combined is the weighted average of income of workers of each reported age group, so if only one age group is omitted for a specific year, average income for that age group can be calculated as a residual. Similarly, for each age, sex, and year the average income of all workers combined is the weighted average of income of workers with all levels of education, so if only one level of education is omitted, average income for that level of education can be calculated as a residual. Rounding errors are introduced in these estimates, because the number of workers is rounded to the nearest thousand persons in each cell; but the errors introduced by this process are small.

[2] E.g., 2. HS, 1 - 3 yrs / no diploma, 1974 – 2009 refers to the combination of *High School, 1 – 3 years* for the period 1974 – 1990 and *High school, no diploma* for the period 1991 – 2009. In section 4 the groups *Some college, no degree* and *Associate degree* for the period 1991 – 2009 are combined, which requires calculating the average earnings of the combined group as a weighted average of the average earnings of the two groups separately. This introduces a small error due to the fact that the numbers in each group are reported only to the nearest thousand.

TABLE 4. SUMMARY TABLE, TREND % CHANGE IN NUMBERS AND EARNINGS IN 2009 $S FOR FULL-TIME EARNERS, 1974 – 2009, BASED ON CPI-U

	Male				Female			
	% ch. #	R sq.	% ch. earn	R sq.	% ch. #	R sq.	% ch. earn	R sq.
1. Elem < 9 yrs, 1974 - 2009								
18 to 24 years	1.0%	0.22	-0.6%	0.14	-0.8%	0.07	0.3%	0.02
25 to 34 years	1.0%	0.31	**-1.0%**	**0.56**	0.8%	0.25	-0.2%	0.09
35 to 44 years	-0.5%	0.06	**-1.0%**	**0.66**	0.7%	0.25	-0.2%	0.07
45 to 54 years	-3.1%	0.74	**-1.1%**	**0.81**	-1.2%	0.35	-0.1%	0.03
55 to 64 years	-4.7%	0.94	**-0.7%**	**0.59**	-3.4%	0.82	0.0%	0.00
65 years and over	-2.5%	0.64	0.9%	0.22	-1.5%	0.24	0.9%	0.24
Total	-1.8%	0.60	**-1.0%**	**0.81**	-1.0%	0.46	-0.1%	0.01
2. HS, 1 - 3 yrs / no diploma, 1974 - 2009								
18 to 24 years	-0.1%	0.00	-0.7%	0.49	0.7%	0.14	-0.3%	0.04
25 to 34 years	0.5%	0.22	**-1.0%**	**0.70**	0.4%	0.12	-0.2%	0.02
35 to 44 years	0.3%	0.05	**-0.9%**	**0.71**	0.1%	0.01	-0.2%	0.14
45 to 54 years	-1.5%	0.46	**-0.9%**	**0.65**	-0.5%	0.44	-0.2%	0.13
55 to 64 years	-2.6%	0.92	-0.4%	0.44	-1.2%	0.65	0.0%	0.00
65 years and over	0.3%	0.03	0.2%	0.03	1.8%	0.44	0.7%	0.19
Total	-0.5%	0.25	**-0.9%**	**0.80**	-0.1%	0.02	-0.2%	0.10
3. HS, 4 yrs / grad 1974 - 2009								
18 to 24 years	-0.9%	0.47	-0.6%	0.47	-2.3%	0.77	-0.3%	0.40
25 to 34 years	-0.1%	0.01	**-0.7%**	**0.71**	-0.5%	0.06	-0.1%	0.10
35 to 44 years	1.5%	0.63	**-0.6%**	**0.70**	1.7%	0.44	0.1%	0.15
45 to 54 years	0.4%	0.15	**-0.4%**	**0.55**	1.7%	0.82	0.3%	0.40
55 to 64 years	0.4%	0.15	**-0.4%**	**0.55**	1.7%	0.82	0.3%	0.40
65 years and over	2.6%	0.79	0.3%	0.05	4.0%	0.91	0.4%	0.24
Total	0.7%	0.64	**-0.4%**	**0.56**	0.8%	0.45	**0.3%**	**0.54**
4. Col, 1-3 yrs / No degree + Assoc. degree 1974 - 2009								
18 to 24 years	2.0%	0.78	-0.6%	0.45	2.1%	0.88	-0.4%	0.37
25 to 34 years	1.6%	0.75	-0.4%	0.40	3.2%	0.73	0.0%	0.02
35 to 44 years	3.7%	0.78	-0.4%	0.40	6.0%	0.83	**0.4%**	**0.62**
45 to 54 years	5.0%	0.92	-0.4%	0.45	7.3%	0.96	**0.6%**	**0.73**
55 to 64 years	3.8%	0.88	-0.2%	0.10	6.1%	0.97	**0.5%**	**0.54**
65 years and over	4.6%	0.88	0.2%	0.02	6.5%	0.93	1.2%	0.42
Total	3.2%	0.93	-0.1%	0.13	4.9%	0.94	**0.5%**	**0.81**

Table continued on next page.

TABLE 4 CONTINUED

	Male				Female			
	% ch. #	R sq.	% ch. earn	R sq.	% ch. #	R sq.	% ch. earn	R sq.
6. Col, 4 yrs / Bachelor's 1974 - 2009								
18 to 24 years	1.3%	0.66	0.0%	0.00	2.1%	0.90	0.2%	0.12
25 to 34 years	1.7%	0.82	0.4%	0.47	3.8%	0.87	**0.8%**	**0.74**
35 to 44 years	4.0%	0.87	0.4%	0.24	6.8%	0.89	**1.3%**	**0.91**
45 to 54 years	4.6%	0.93	0.1%	0.05	7.7%	0.97	**1.3%**	**0.83**
55 to 64 years	4.2%	0.90	0.0%	0.00	6.7%	0.94	**1.0%**	**0.68**
65 years and over	4.8%	0.91	0.4%	0.13	6.1%	0.83	2.0%	0.38
Total	3.3%	0.97	**0.5%**	**0.53**	5.4%	0.97	**1.2%**	**0.91**
7. Col, 5 yrs or more / > Bachelor's 1974 - 2009								
18 to 24 years	-3.0%	0.24	1.0%	0.24	-1.0%	0.07	0.8%	0.30
25 to 34 years	-1.1%	0.40	**0.8%**	**0.69**	2.2%	0.58	**1.1%**	**0.86**
35 to 44 years	1.0%	0.27	**1.1%**	**0.66**	4.2%	0.74	**1.5%**	**0.77**
45 to 54 years	3.2%	0.91	**1.0%**	**0.65**	6.2%	0.96	**1.3%**	**0.88**
55 to 64 years	3.9%	0.91	0.9%	0.49	6.0%	0.92	**1.3%**	**0.81**
65 years and over	4.5%	0.88	1.0%	0.34	5.8%	0.78	1.8%	0.40
Total	1.7%	0.79	**1.2%**	**0.79**	4.3%	0.94	**1.5%**	**0.89**
8. Total labor force 1974 - 2009								
18 to 24 years	0.2%	0.06	-0.5%	0.38	-0.1%	0.01	0.0%	0.01
25 to 34 years	0.7%	0.43	-0.2%	0.10	1.8%	0.63	**0.7%**	**0.83**
35 to 44 years	2.1%	0.81	0.2%	0.19	3.6%	0.82	**1.1%**	**0.95**
45 to 54 years	2.4%	0.89	**0.5%**	**0.64**	4.1%	0.97	**1.3%**	**0.93**
55 to 64 years	1.3%	0.51	0.8%	0.78	3.0%	0.87	**1.3%**	**0.90**
65 years and over	2.5%	0.80	**1.4%**	**0.81**	4.0%	0.91	**1.5%**	**0.76**
Total	1.5%	0.95	**0.4%**	**0.57**	2.8%	0.95	**1.1%**	**0.95**

Focusing just on the total groups (all ages combined) for each education class, we see that females earnings have generally grown faster than male earnings; those differences seem to be high enough to consider projecting female earnings growth rates to be higher than males for the future.

VIII. CONCLUSION

I have shown that the real earnings of college graduates have increased considerably faster than earnings for those with less education, and that in the context of elementary macroeconomic theory this is consistent with the relative growth of the skilled and unskilled labor forces only because of technical change that increases the reward to college graduates. More detailed studies by labor economists have identified as the most plausible explanation a long-run *skill-biased* technical change (SBTC), coupled with falling price for capital equipment and a consequent sharp increase in the capital equipment intensity of production. Forensic economists must ask whether this SBTC will plausibly continue over the period for which earnings are to be forecast. My own practice is to project continuation of the trend but at a more moderate pace than in the recent past, and the crude macroeconomic calculations performed here seem to support that judgment. But *micro*economic projection for a specific individual requires study of the pattern of earnings growth for the particular mix of sex, age, and education.

IX. DATA APPENDIX

Not included in this draft. The data used and their sources are available from the author.

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