

Analyzing Skilled and Unskilled Labor Efficiencies in the US

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Abstract

In this paper, I analyze the time paths of the efficiencies of skilled and unskilled labor in a production framework where skilled and unskilled labor are imperfect substitutes. Their implications for economic growth and wage inequality in the US between 1950 and 2005 present two main findings. First, although skilled labor efficiency has a strong upward trend, I find no evidence of acceleration in its growth rate to support the common view that there has been an acceleration in the new skilled-biased technologies. Second, beginning around 1970, there has been a decline in the absolute level of the efficiency of unskilled labor, implying that the decline has played a significant role in the overall productivity slowdown and the substantial widening in the U.S. wage structure.

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1 Introduction

This paper investigates how skilled and unskilled labor efficiencies have evolved since 1950. Toward this end, I extend the standard two-factor production function to a four-factor production function with capital structure, capital equipment, skilled labor, and unskilled labor, where these factors are imperfect substitute with each other. Assuming that markets are competitive and parameters of the model are known, I derive time series of capital equipment, skilled, and unskilled labor efficiencies from the data.

The paper is motivated by two important facts. First, previous studies that investigate the sources of US economic growth decompose changes in output into changes in factors of production and change in overall efficiency (total factor productivity). These studies also assume that skilled and unskilled labor are perfect substitutes (see, e.g., Jones, 2002; and Ha and Howitt, 2007). Considering a more general general production framework in which inputs are imperfect substitute and decomposing overall efficiency into capital, skilled, and unskilled efficiencies provide a better understanding of the sources of US growth. Second, over the last 50 years in the US, there have been dramatic changes in the relative supply of skills and the skill premium, defined as the ratio of the skilled labor wage to the unskilled labor wage. As shown in Figure 1, despite the rapid increase in the relative supply of skills, there has been a substantial increase in the skill premium over this period. Another aspect of Figure 1 is that the skill premium has trended sharply upward since the early 1980s. This pattern underlines the common view that new technologies have been skill-biased and there has been an acceleration in skill-biased technical change.¹ Naturally, one may wonder how the efficiencies of skilled and unskilled labor have changed over this period.

The main findings of this paper can be summarized as follows. First, I find that although skilled labor efficiency has a strong upward trend, there is no evidence of acceleration in its growth rate. Interestingly, I also find that beginning around 1970, there has been a *decline*

¹The literature on this subject is vast. Important contributions are Bound and Johnson (1992), Katz and Murphy (1992), and Acemoglu (1998). See Acemoglu (2002) for a more comprehensive review of the literature.

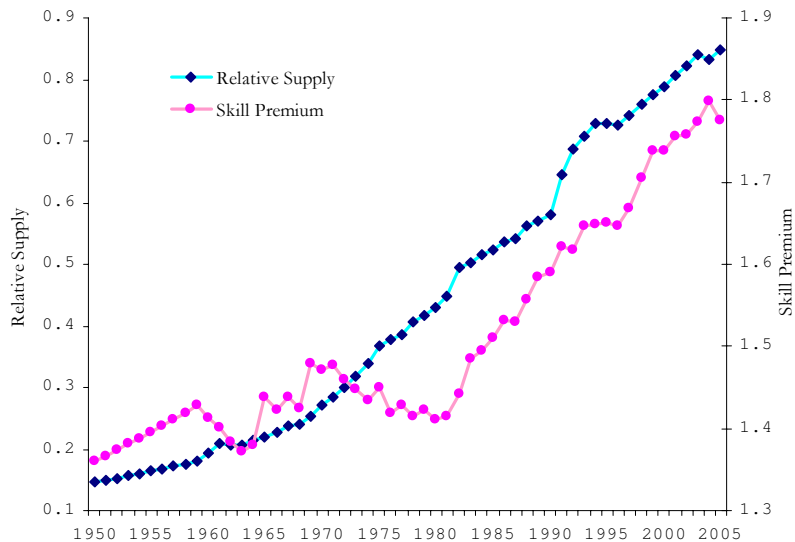


FIGURE 1. Relative Supply of Skills vs. Skill Premium

Notes: The skilled labor class consists of college or college-plus workers and half of the workers with some college; and the unskilled labor class consists of high school dropouts, high school graduates, and half of the workers with some college. The relative supply of skills is defined as ratio of total hours worked by skilled labor to that by unskilled labor.

in the absolute level of the efficiency of unskilled labor, although the magnitude of the decline is relatively less when there is a higher elasticity of substitution between skilled and unskilled labor. This is in sharp contrast to the period of 1950-70, during which unskilled labor efficiency was generally rising. Finally, I find that the time paths of the capital equipment efficiency depends on the elasticity of substitution between capital equipment and skilled labor.

This paper is related to the accounting literature that investigates the sources of growth in the U.S. economy.² The paper contributes to this literature by decomposing changes in overall efficiency into changes in efficiencies of capital (equipment), skilled and unskilled labor.³ In backing out the actual levels of efficiencies from the data, this paper follows

²See Solow (1957), Jones (2002), and Jorgenson (2005), among many others.

³Growth in the efficiency of skilled labor is the largest contributor to output per hour growth in this decomposition, accounting for between about 50 and 130 percent of growth (depending on the exact value of parameters in the model, the definition of skilled labor, and the time period considered in the exercise), while changes in the efficiency of unskilled labor accounts for between -90 and 50 percent of growth (see section 3.4).

Caselli and Coleman (2002) who, applying a different production framework to time series data from the US over 1963-1992, find that throughout this period efficiency of skilled labor and capital have risen, while the efficiency of the unskilled labor has fallen since the early 1970's.⁴ This paper differs from theirs in two important aspects. First, this paper considers a more general production function in which there are two different types of capital (structure and equipment) as opposite to a single aggregate capital input in Caselli and Coleman (2002). As will be shown later, the time paths of capital equipment and skilled labor obtained from this general production framework are different from those in Caselli and Coleman (2002).⁵ Second, this paper conducts extensive accounting exercises to investigate the implications of the evolutions of efficiencies on the economic growth and wage inequality in the US.

The present study is also related to the wage inequality literature that typically addresses the determinants of the dramatic changes in the U.S. skill premium (see Katz and Murphy, 1992; Krusell et al., 2000; and Autor et al., 2008, among many others). These studies address the roles of different types of technical changes on the skill premium by estimating an econometric specification. In this paper, on the other hand, I derive the time series behavior of skilled and unskilled labor efficiencies directly from the data, using a few assumptions widely accepted in the literature.

The rest of this paper is organized as follows. Section 2 introduces the benchmark production framework that underlies the analysis. Section 3 presents the quantitative analysis in which the main features of the data are explained and the main results are presented. Section 4 studies robustness of results and compare them to those in the previous studies.

⁴Under a different production framework, Caselli and Coleman (2006) uses the same methodology to study cross-country differences in skilled and unskilled labor efficiencies when skilled and unskilled labor are imperfect substitutes. They show that higher-income countries use skilled labor more efficiently than lower-income countries, but they use unskilled labor relatively less efficiently. This paper shows that the efficiency of unskilled labor is not monotonically declining with an increase in the income level.

⁵Moreover, this paper uses a considerably longer time series data, which provides a better picture of the evolutions of efficiencies. For example, the efficiency of unskilled labor has generally risen until the early 1970's; and the magnitude of the decline after the early 1970's inversely depends on the elasticity of substitution between two different types of labor.

Finally, section 5 offers some concluding remarks.

2 Modeling Production

I consider a production function which is Cobb-Douglas over capital structure (K_b), and a nested constant-elasticity-of substitution (CES) function of capital equipment (K_e), skilled labor (L_s), and unskilled labor (L_u) as in Krusell et al. (2000):

$$Y_t = K_{bt}^{\alpha_b} \{ [(A_{et}K_{et})^{\rho_2} + (A_{st}L_{st})^{\rho_2}]^{\frac{\rho_1}{\rho_2}} + (A_{ut}L_{ut})^{\rho_1} \}^{\frac{1-\alpha_b}{\rho_1}}, \quad (1)$$

where $\alpha_b \in (0, 1)$ represents the share of capital structure in total output, and ρ_1 and ρ_2 are two parameters that drive the elasticity of substitution between skilled labor, equipment, and unskilled labor. The elasticity of substitution between skilled labor (or equipment) and unskilled labor is $\sigma_1 = 1/(1 - \rho_1)$, and the elasticity of substitution between equipment and skilled labor is $\sigma_2 = 1/(1 - \rho_2)$. In this specification, A_e , A_s , and A_u represent the efficiency of equipment (or equipment augmenting technology), the efficiency of the efficiency of skilled labor (or skilled labor augmenting technology), and represents the efficiency of unskilled labor (unskilled labor augmenting technology), respectively.⁶

Factor markets are assumed to be competitive so that each factor earns its marginal product. The first order conditions with respect K_e , L_s , and L_u yield (upon rearranging terms)

$$\frac{r_e K_e}{w_s L_s} = \left(\frac{A_e K_e}{A_s L_s} \right)^{\rho_2}, \quad (2)$$

$$\frac{w_s L_s}{w_u L_u} = \left[1 + \left(\frac{A_e K_e}{A_s L_s} \right)^{\rho_2} \right]^{\frac{\rho_1 - \rho_2}{\rho_2}} \left(\frac{A_s L_s}{A_u L_u} \right)^{\rho_1}, \quad (3)$$

where r_e represents the return to capital equipment (i.e., real interest rate plus the rate of depreciation); and w_s and w_u are the wage rates of skilled and unskilled labor, respectively.

⁶ Although the production function in (1) is similar to that in Krusell et al. (2000), there is an important distinction between the two functions. The efficiency of capital equipment is constant in Krusell et al., while it changes over time in my specification.

Given data on output, factor inputs, factor prices, and assuming that parameters α_b , ρ_1 , and ρ_2 are known, equations (1), (2), and (3) constitute a system of three equations with three unknowns A_e , A_s , and A_u , which has a closed-form solution:

$$A_e = \left(\frac{Y}{K_e}\right) \left(\frac{Y}{K_b}\right)^{\frac{\alpha_b}{1-\alpha_b}} \left(\frac{\alpha_e}{\alpha_e + \alpha_s}\right)^{\frac{1}{\rho_2}} \left(\frac{\alpha_e + \alpha_s}{1 - \alpha_b}\right)^{\frac{1}{\rho_1}}, \quad (4)$$

$$A_s = \left(\frac{Y}{L_s}\right) \left(\frac{Y}{K_b}\right)^{\frac{\alpha_b}{1-\alpha_b}} \left(\frac{\alpha_s}{\alpha_e + \alpha_s}\right)^{\frac{1}{\rho_2}} \left(\frac{\alpha_e + \alpha_s}{1 - \alpha_b}\right)^{\frac{1}{\rho_1}}, \quad (5)$$

$$A_u = \left(\frac{Y}{L_u}\right) \left(\frac{Y}{K_b}\right)^{\frac{\alpha_b}{1-\alpha_b}} \left(\frac{\alpha_u}{1 - \alpha_b}\right)^{\frac{1}{\rho_1}}, \quad (6)$$

where α_j represents the share of factor j in total output.⁷

Having A_e , A_s , and A_u , one can easily implement a growth accounting exercise to assess their importance to output growth. Taking the logarithm of both sides in equation (1) and differentiating with respect to time yields

$$g_Y = \varepsilon_b g_{K_b} + \varepsilon_e g_{K_e} + \varepsilon_s g_{L_s} + \varepsilon_u g_{L_u} + \varepsilon_e g_{A_e} + \varepsilon_s g_{A_s} + \varepsilon_u g_{A_u},$$

where g_x represents the growth rate of variable x and $\varepsilon_x = (\partial Y / \partial x)(x/Y)$ is the elasticity of x with respect to output Y . It easily follows that $\varepsilon_j = \alpha_j$, with $j = b, e, s$, and u . Let N_t denote the total labor hours worked, then the above equation yields:

$$g_y = \beta_b g_{k_b} + \beta_e g_{k_e} + \beta_s g_{\ell_s} + \beta_u g_{\ell_u} + \beta_e g_{A_e} + \beta_s g_{A_s} + \beta_u g_{A_u}, \quad (7)$$

where $\beta_j = \alpha_j / (\alpha_s + \alpha_u)$ and $y \equiv Y/N$, $k_b = K_b/Y$, $k_e = K_e/Y$, and $\ell_j = L_j/N$. The motivation for considering changes in the capital-output ratio rather than changes in capital-labor ratio is to assign the long-run effects of changes in capital to this variable (see, for example, Jones, 2002).

Equation (7) decomposes labor productivity (output per hour) into several components that have specific interpretations. The terms, $\beta_b g_{k_b}$ and $\beta_e g_{k_e}$ measure the contribution

⁷Using (2) in (1) yields an equation with two unknowns A_s and A_u . Using (2) in (3) yields another equation for A_s and A_u . Solving these two equations for A_s and noticing that $r_e K_e + w_s L_s + w_u L_u = (1 - \alpha_b)Y$ yields (5).

of capital deepening to labor productivity growth. The terms $\beta_s g_{\ell_s}$ and $\beta_u g_{\ell_u}$ represent the contributions of changes in per hour inputs of skilled and unskilled labor to the productivity growth. The final terms, $\beta_e g_{A_e}$, $\beta_s g_{A_s}$, and $\beta_u g_{A_u}$, measure the contributions of equipment, skilled, and unskilled augmenting efficiency changes to labor productivity growth, respectively. The discrete time approximation of (7) is given by

$$\hat{y}_t = \bar{\beta}_{bt} \hat{g}_{k_{bt}} + \bar{\beta}_{et} \hat{g}_{k_{et}} + \bar{\beta}_{st} \hat{\ell}_{st} + \bar{\beta}_{ut} \hat{\ell}_{ut} + \bar{\beta}_{et} \hat{A}_{et} + \bar{\beta}_{st} \hat{A}_{st} + \bar{\beta}_{ut} \hat{A}_{ut}, \quad (8)$$

where $\hat{x}_t = \ln x_t - \ln x_{t-1}$ represents the growth rate of variable x in year t and $\bar{\beta}_{jt} = 0.5(\beta_{j,t-1} + \beta_{j,t})$.

3 Quantitative Analysis

In this section, I will apply the key results presented in the previous section to investigate the effects of capital, skilled, and unskilled labor efficiencies on economic growth and the skill premium since 1950. I start with the construction of key variables used in the model. The appendix provides a complete description of the data sets and construction of aggregate variables.

3.1 The Data

The data on output and capital are obtained from the Bureau of Economic Analysis (BEA), they are in 2000 chain-dollars.⁸ The key point in this exercise is the construction of the skilled and unskilled labor input and wages. The sources of labor input data are from the Census Surveys 1950 and 1960, and the March Current Population Surveys (CPSs) from 1962 to 2006. Since wages and labor input data in the survey refer to one year earlier,

⁸Krusell et al. (2000) criticize the BEA capital series for not properly taking quality adjustment into account, and they construct an alternative capital equipment stocks based on Gordon's (1990) price deflators for investment in equipment and machinery. However, the BEA has substantially revised the series by increasingly using the hedonic price techniques for quality adjustment when measuring price changes (Wasshausen and Moulton, 2006). Furthermore, the use of Gordon's series does not come without any concession. First, the series are only available until 1983, which requires imputation of price indexes for the remaining 22 years. Second, Gordon's series declines too rapidly after 1975 suggesting considerable measurement errors (Acemoglu, 2002).

the sample spans the period 1949-2005.⁹ I consider all employed people between 16 and 70 years old, excluding self-employed workers.

Construction of the series for skilled and unskilled labor is accomplished in two steps. First, the data in each year are divided into 72 distinct labor groups (characterized by sex, years of education, and years of experience) and their average labor inputs (measured as total hours) and hourly wages are calculated using census sampling weights. In the second step, I sort these groups into skilled and unskilled labor. Following much of the literature, I assume that everyone who has at least 16 years of schooling is considered as skilled, and those who have fewer years of schooling are classified as unskilled. I will later consider an alternative classification scheme used by Autor et al. (2008) in which the skilled labor class consists of college or college-plus workers and half of the workers with some college; and the unskilled labor class consists of high school dropouts, high school graduates, and half of the workers with some college. But qualitative results remain the same.

Groups within a class are assumed to be perfect substitutes and, following the standard practice in this literature, I use group relative hourly wages as weights for the aggregation of labor inputs into skilled and unskilled classes. The basic idea is based on the assumption that relative wages equal relative qualities of labor.¹⁰ Thus, labor input is quality-adjusted.

The corresponding *quality-adjusted* average wage rate for each class is calculated as $w_{jt} = W_{jt}/L_{jt}$, where W_{jt} is the total compensation paid to the class j workers (see Appendix). The rental price of capital, r_e , is calculated by using the Hall-Jorgenson formula: $r_e = (i - \pi_k^e + \delta)(1 - z\tau)/(1 - \tau)$, where i is the nominal after corporate tax interest rate, π_k^e is the expected rate of inflation in capital equipment price, δ is the rate of economic depreciation, τ is corporate tax rate, and z is the present value of depreciation deduction on a \$1 investment. Some researchers (e.g., Caselli and Coleman, 2002) use the Treasury-

⁹Since the Census Surveys are conducted every ten years, the data between 1950-1960 are not available. Also, there is no CPS data before 1962 and the 1963 CPS does not have education data. For intervening years, I impute each *group*'s data by log-linearly interpolating the same group's data in available neighboring surveys.

¹⁰Labor input is usually called *efficiency-adjusted* labor (e.g. Katz and Murphy, 1992). However, in this paper *efficiency* refers to the measured values of A_e , A_s , and A_u .

bills (T-bills) nominal interest rate as a proxy for i . However, the T-bills rates do not cover risk-premium; hence, I use corporate bond rates as a measure of the nominal interest rate.¹¹ I set $\delta = 0.125$, and following Gale and Orszag (2005), $\tau = 0.35$ and $z = 0.83$.

To construct the A_e , A_s , and A_u series, the three parameters must be known— α_b , ρ_1 , and ρ_2 . The parameter α_b measures the capital structures share and I set it to 0.12 consistent with previous estimates (Greenwood et al., 1997).

As indicated before, the parameter ρ_1 govern the elasticity of substitution between skilled and unskilled workers (σ_1) and there is a large labor economics literature focused on estimating its value. The common consensus is that σ_1 is around 1.5 (Acemoglu, 2002). For example, using a production function with no capital inputs, Katz and Murphy (1992), based on the CPSs data over the period 1963-87, find that the elasticity is 1.41; and Autor et al. (2008) extend the period to 2005, and report that it is about 1.6. Krusell et al. (2000), using a production function similar to mine, find that this elasticity is about 1.7. Indeed, based on various econometric estimates, Autor et al. (1998) conclude that this elasticity is very unlikely to be greater than 2. In my main analysis, I will set $\rho_1 = 0.33$ ($\sigma_1 = 1.5$), but I will later present results based on $\rho_1 = 0.5$, ($\sigma_1 = 2$).

The parameter ρ_2 drives the elasticity of substitution between capital equipment and skilled labor. Estimates of the elasticity of substitution between capital (which may contain structures) and skill labor are usually less than 1.2 (Hammermesh, 1993). Krusell et al. (2000), for example, find that $\rho_2 = -0.495$, implying that the elasticity of substitution between equipment and skilled labor is 0.67. In subsequent analysis, I consider two possibilities: $\rho_2 = -0.5$ ($\sigma_2 = 0.67$) and 0.25 ($\sigma_2 = 1.25$), although $\rho_2 < 0$ seems a more plausible choice in the current context (since capital equipment and capital structure enters separately into the production function).

¹¹In particular, I use Moody's AAA corporate bond rates (<http://www.federalreserve.gov/releases/h15/data.htm>). I use simple moving average of the last two years inflation as a proxy for expected inflation.

3.2 Main Results

Figures 2.a and 2.b plot the corresponding time paths of (log) capital equipment, skilled and unskilled labor efficiencies. There are several interesting aspects to note in these figures, and I start with analyzing the time paths of skilled labor. First, although there is an increase in skill premium since the early 1980s (see Figure 1), there is *no* acceleration in A_s . Indeed, According to Figure 2.a, the efficiency of skilled labor has grown more slowly since the mid 1980s: the average annual growth rate of A_s between 1950 and 1985 is about 7.8%, while it is 2.5% between 1985 and 2005.¹² These results question the validity of the standard view that the increased wage inequality observed since the early 1980 have resulted from an acceleration in skill-biased technical change. If there had been an acceleration in skill-biased technical change, why is there no signature of it as could be demonstrated by a substantial increase in the growth rate of A_s in both figures?

Second, A_u has declined since around 1970.¹³ The average annual growth rate of A_u between 1950 and 1970 is 1%, while it is -1.4% since 1970.¹⁴ Had A_u continued to grow at 1.0% annually after 1970, the skill-premium would have been about 24 percent lower than the actual premium in 2005. The output would have been about 47 percent higher than the actual output in 2005.

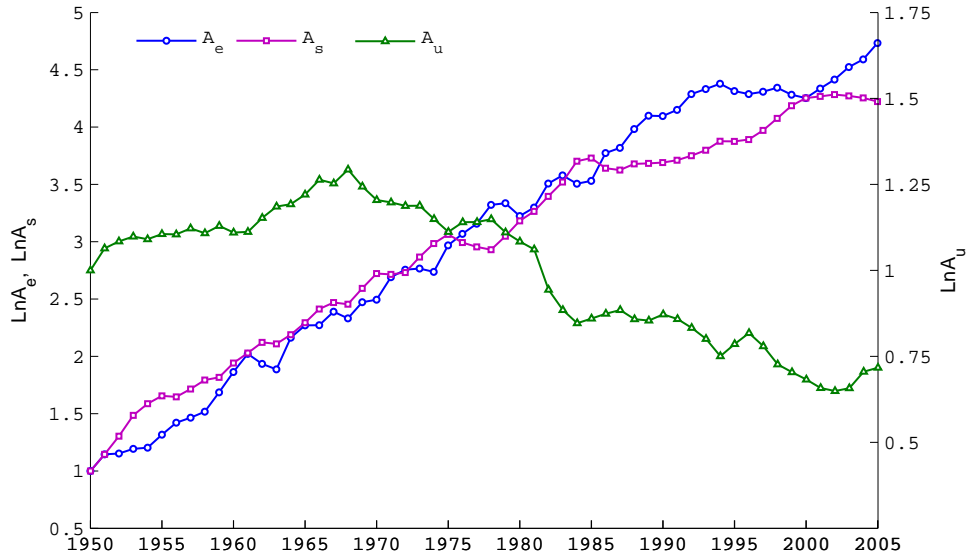
Finally, although A_e has a strong upward trend with an average annual growth rate of 6.8% in Figure 2.a, its trend become less clear when capital is an imperfect substitute

¹²For example, had A_s continued to grow at 7.8% annually after 1985, the skill-premium and output would have been about 14% and 45%, respectively, higher than the corresponding actual values in 2005.

¹³The decline in A_u is consistent with Greenwood and Yorukoglu (1997) who argue that new ITs required a substantial period of learning by workers who would work with the technology; and during this learning process, productivity was depressed as labor adapted to more powerful new technologies. Given that unskilled labor is not equipped with necessary training to use the new technologies, their productivity might even decline upon implementing them. Another explanation for this decline is that the average ability level of workers in both classes might have declined. This can happen, for example, when able people who would otherwise work in less skill-intensive jobs get more education in response to increases in the college premium, and then subsequently work in skill-intensive jobs. As a result, over time the less skill-intensive sector will be populated with less able workers. At the same time, the average ability of workers in skill-intensive jobs may also decline, if the new entrants have lower ability than the average ability of workers in skill-intensive jobs.

¹⁴According to equation (6), A_u does not depend on the parameter ρ_2 . Thus, the time plots of A_u in both figures are identical.

a. $\rho_1 = 0.33$ and $\rho_2 = -0.50$.



b. $\rho_1 = 0.33$ and $\rho_2 = 0.25$.

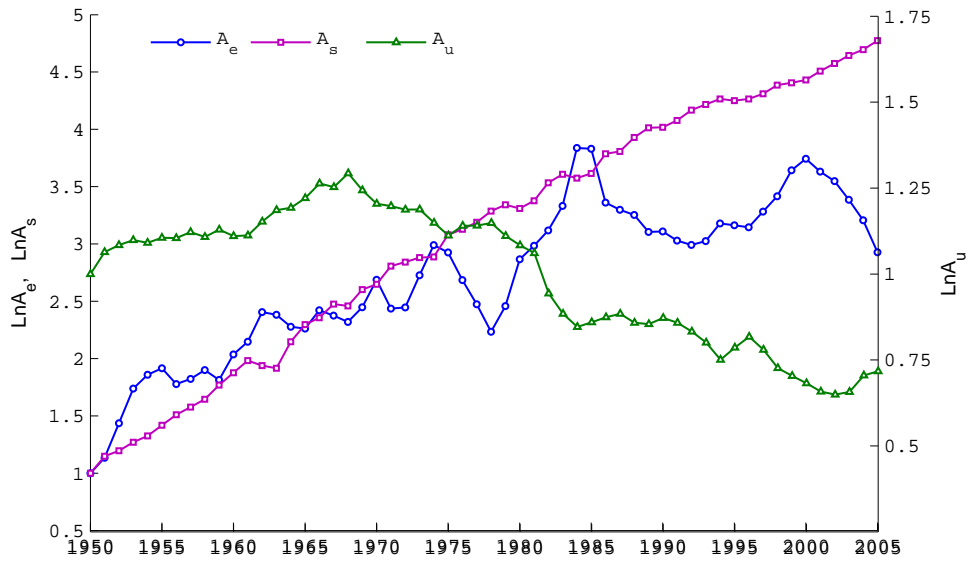


FIGURE 2. Time Series Graphs of $\ln A_e$, $\ln A_s$, and $\ln A_u$ (1950=1)

TABLE 1. Accounting For US Growth (%) with $\rho_1 = 0.33$ and $\rho_2 = -0.5$.

Period	Output per Hour	Capital		Contribution from Labor			Efficiency	
	\hat{y}	$\bar{\beta}_b \hat{k}_b$	$\bar{\beta}_e \hat{k}_e$	$\bar{\beta}_s \hat{\ell}_s$	$\bar{\beta}_u \hat{\ell}_u$	$\bar{\beta}_e \hat{A}_e$	$\bar{\beta}_s \hat{A}_s$	$\bar{\beta}_u \hat{A}_u$
1950-2005	2.1	-0.1	0.1	0.6	-0.2	0.6	1.4	-0.3
	(100)	(-6)	(4)	(29)	(-12)	(29)	(68)	(-14)
1950-1970	2.9	-0.1	0.0	0.4	-0.2	0.5	1.4	0.9
	(100)	(-4)	(2)	(22)	(9)	(16)	(47)	(30)
1970-2005	1.6	0.1	0.1	0.7	-0.3	0.7	1.5	-1.0
	(100)	(7)	(7)	(34)	(-14)	(43)	(94)	(-65)

Notes: This table reports the growth accounting decomposition based on equation (8), in which \hat{x} represents the average annual growth rate of a variable x . Numbers in parentheses represent relative contributions in percentage.

with skilled labor (see Figure 2.b). Since the early 1980s, there is no clear trend in A_e . The average annual growth rate of A_e between 1950 and 1980 is about 6.2%, while it is about 0.2% over the period 1983-2005. Interestingly, had A_e continued to grow at 6.2% annually after 1980, the skill-premium and output (and hence, per capita income) would have been about 3% and 17%, respectively, higher than the corresponding actual values in 2005.

I now turn to the accounting exercises. Table 1 reports the growth accounting exercises based on equation (5) with $\rho_1 = 0.33$ and $\rho_2 = -0.5$. The contribution of factor inputs to labor productivity growth over 1950-2005 is about 15 percent. The remaining 85 percent of growth is attributed to changes in efficiencies. This effect itself is the sum of three components. First, growth in the efficiency of capital equipment accounts for about 30 percent of output growth. Second, growth in the efficiency of skilled labor is the largest contributor to productivity growth in this decomposition, accounting for about 68 percent of output growth. Finally, changes in the efficiency of unskilled labor accounts for about -15 percent of growth. Table also reports the accounting exercises for different time periods. Notice that change in the efficiency of unskilled labor between 1970 and 2005 has substantially negative contribution to output growth.

It is worth for noticing that the contribution of each class of labor to output growth can further be decomposed into two sub-components. To see this, recall that the labor input is quality-adjusted: $L_{jt} = q_{jt}N_{jt}$, where q_{jt} represents the quality index of j -type labor, and N_{jt} is the total hours worked by the corresponding individuals. This further can be written as $\ell_j = q_j n_j$, where $n_j \equiv N_j/N$ is the fraction of total (raw) labor used by j -type labor. Thus, $\bar{\beta}_j \hat{q}_j$ represents the contributions of changes in the quality of j -type labor to output per hour growth, and $\bar{\beta}_j \hat{n}_j$ is the contributions of labor reallocation to output growth. Accounting exercises show that the contribution of changes in quality of skilled (unskilled) labor to output growth between 1950 and 2005 is about 0 (7) percent; while while the contribution from the reallocation of workers into skilled (unskilled) class is about 29 (-19) percent.¹⁵

How much will the above accounting results change, if $\rho_2 = 0.25$? Equations (4)-(6) imply that ρ_2 only affects A_e and A_s . Thus, contributions of factor inputs and A_u to output growth would be identical with those reported in Table 1. Only contributions from A_s and A_u will be different. In this case, growth in the efficiency of capital equipment accounts for about 11 percent of the average annual output per hour growth between 1950-2005, while changes in the efficiency of skilled labor accounts for about 87 percent of growth.¹⁶

4 Robustness and Comparison to Previous Works

4.1 Alternative Classification of Labor

The analysis presented in the previous section is based on a classification in which the skilled labor class consists of college or college-plus workers. In this section, I consider an

¹⁵Similarly, the average contribution of changes in quality of skilled (unskilled) labor to output growth between 1950 and 1970 is about -1 (4) percent; while the contribution from the reallocation of workers into skilled (unskilled) class is about 16 (-10) percent. During 1970-2005, however, the average contribution of changes in quality of skilled (unskilled) labor to output growth between 1950 and 1970 is about 0 (10) percent; while the contribution from the reallocation of workers into skilled (unskilled) class is about 45 (-28) percent.

¹⁶Growth in the efficiency of capital equipment accounts for about 18 (7) percent of the average annual output per hour growth over 1950-70 (1970-2005), while changes in the efficiency of skilled labor accounts for about 46 (130) percent of growth over the corresponding period.

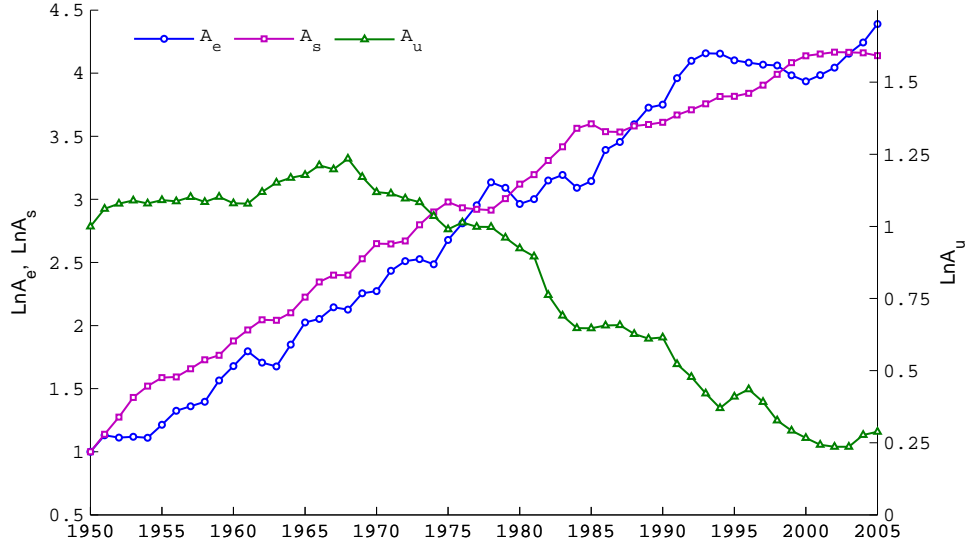


FIGURE 3. Plots of $\ln A_e$, $\ln A_s$, and $\ln A_u$ under Alternative Classification of Labor.

Notes: These figures represent the time paths of the (log) efficiencies of capital equipment, skilled and unskilled labor with $\rho_1 = 0.33$ and $\rho_2 = -0.5$. The (log) initial values are normalized to 1.

alternative classification used by Autor et al. (2008) in which the skilled labor class consists of college or college-plus workers and half of the workers with some college; and the unskilled labor class consists of high school dropouts, high school graduates, and half of the workers with some college. For the sake of brevity, I only present results based on $\rho_1 = 0.33$ and $\rho_2 = -0.5$. Qualitative implications based on $\rho_1 = 0.33$ and $\rho_2 = 0.25$ are similar to those presented in this section (and available upon request).

Figure 3 plots the time paths of efficiency indexes. These plots are similar to those in Figure 2.a, except that the decline in A_u is more substantial than that in Figure 2.a. Moreover, compared to the time path of A_u in Figure 2.a, A_u grew more slowly between 1950 and 1970. The average annual growth rates of A_u over the two periods 1950-1970 and 1970-2005 are 0.6 and -2.4 percents, respectively; whereas they are 1.0 and -1.4 percents in Figure 2.a. Table 2 presents accounting results based on equation (8). Although the contributions of subcomponents are different, the total contribution of factor inputs, and

TABLE 2. Accounting For US Growth (%) with $\rho_1 = 0.33$ and $\rho_2 = -0.5$.

Period	Output per Hour	Capital		Contribution from Labor			Efficiency	
	\hat{y}	$\bar{\beta}_b \hat{k}_b$	$\bar{\beta}_e \hat{k}_e$	$\bar{\beta}_s \hat{\ell}_s$	$\bar{\beta}_u \hat{\ell}_u$	$\bar{\beta}_e \hat{A}_e$	$\bar{\beta}_s \hat{A}_s$	$\bar{\beta}_u \hat{A}_u$
1950-2005	2.1	-0.1	0.1	0.8	-0.4	0.6	1.8	-0.7
	(100)	(-6)	(4)	(39)	(-21)	(27)	(90)	(-33)
1950-1970	2.9	-0.1	0.0	0.6	-0.3	0.4	1.8	0.5
	(100)	(-4)	(2)	(20)	(-11)	(14)	(63)	(17)
1970-2005	1.6	0.1	0.1	0.9	-0.5	0.6	1.9	-1.4
	(100)	(7)	(7)	(60)	(-33)	(40)	(122)	(-90)

Notes: This table reports the growth accounting decomposition based on an alternative definition of skill. \hat{x} represents the average annual growth rate of a variable x . Numbers in parentheses represent relative contributions in percentage.

hence, efficiencies, remains almost the same.

4.2 Higher Substitution Between Skilled and Unskilled Labor

Figure 4 presents the time paths of capital equipment, skilled unskilled labor efficiencies when the elasticity of substitution between skilled and unskilled labor is 2 (or $\rho_1 = 0.5$).¹⁷ Although these plots are similar to those in Figure 2.a, there are important differences between two figures. First, the decline in A_u after 1970 is not as substantial as that in Figure 2.a. Moreover, compared to the time path of A_u in Figure 2.a, A_u grew relatively more rapidly until 1970. The average annual growth rates of A_u over the two periods 1950-1970 and 1970-2005 are 1.8 and -0.2 percents, respectively; whereas they are 1.0 and -1.4 percents in Figure 2.a. Second, compared to the time paths of A_e and A_s in Figure 2.a, they have grown more slowly. For example, the average annual growth rates of A_e and A_s between 1950 and 2005 are 3.7 and 4.6 percents, respectively; while they are 6.8 and 5.9 percents in Figure 2.a. Consistent with these observations, the accounting results reported in Table 3 represent a more positive contribution from A_u to the labor productivity growth

¹⁷For brevity, I only present results based on $\rho_2 = -0.5$; but the qualitative implications of the analysis based on $\rho_2 = 0.25$ are similar to that presented in this section.

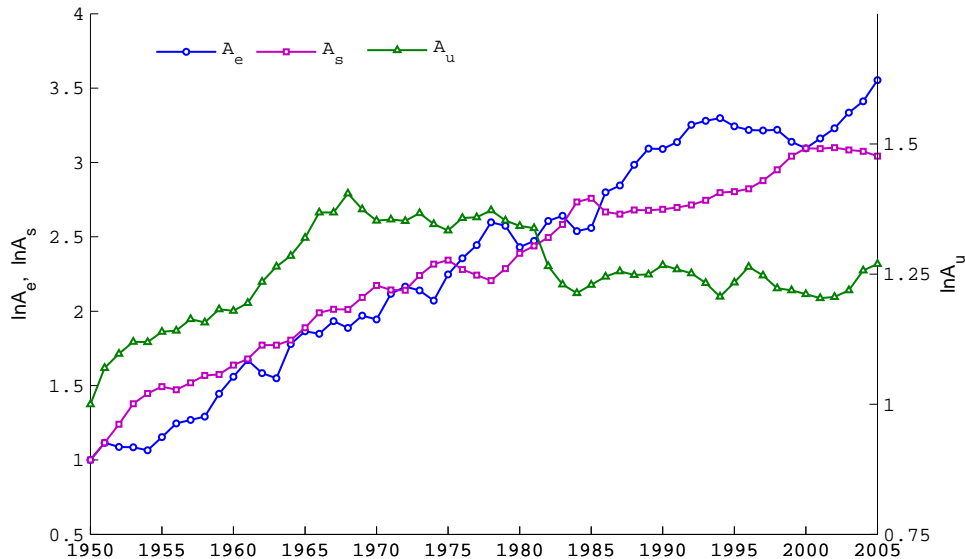


FIGURE 4. Efficiency Indexes Under $\rho_1 = 0.5$ and $\rho_2 = -0.5$ (1950=1).

in until 1970, and a less negative contribution during the post 1970 period.

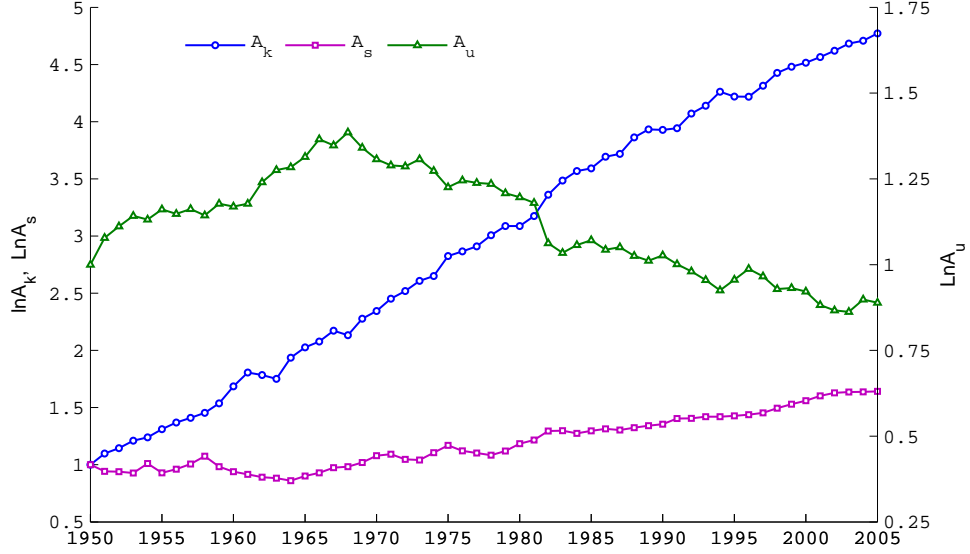
4.3 Alternative Production Specifications

Setting $\alpha_b = 0$ and replacing K_e with $K = K_b + K_e$ in equation (1) yields the production function used by Caselli and Coleman (2002). Thus, this presentation assumes that capital structure and capital equipment are perfect substitute, which does not seem plausible on a priori grounds.

Figure 5.a plots the time paths of (log) capital equipment, skilled and unskilled labor efficiencies under $\rho_1 = 0.33$ and $\rho_2 = -0.5$ (i.e., capital-skill complementarity). Although time trends of A_k and A_u in Figure 5.a are somewhat similar to those in Figure 2.a, the time path of skilled labor is dramatically different from that in Figure 2.a. The average annual growth rate of A_s between 1950 and 2005 is about 1.2 percent, and A_s has been mostly unchanged since the late 1970s.¹⁸

¹⁸Unfortunately, Caselli and Coleman (2002) do not report results based on this specification, so I can not make a direct comparison. However, they claim that the time trends of A_s and A_u based on a capital

a. $\rho_1 = 0.33$ and $\rho_2 = -0.50$.



b. $\rho_1 = 0.33$ and $\rho_2 = 0.25$.

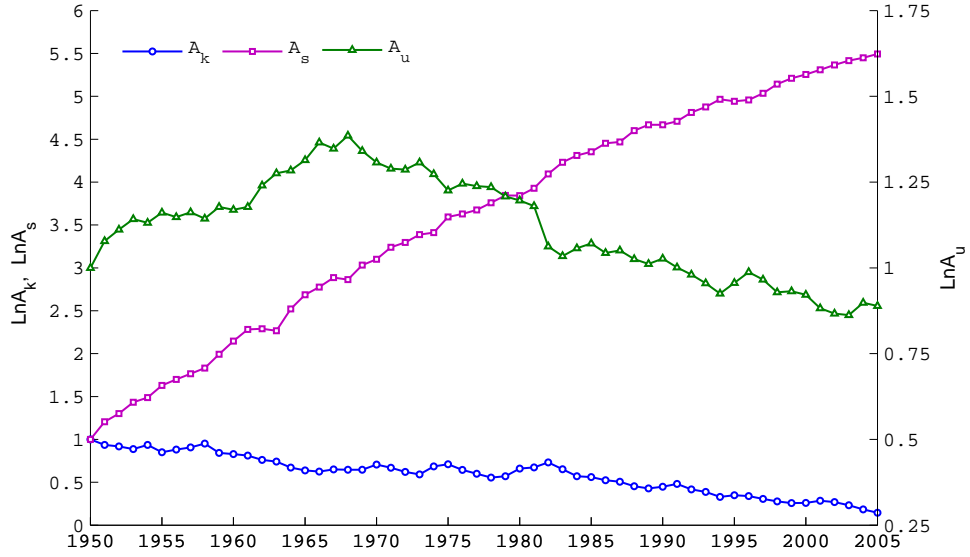


FIGURE 5. Time Series Graphs of $\ln A_k$, $\ln A_s$, and $\ln A_u$ (1950=1)

TABLE 3. Accounting For US Growth (%) with $\rho_1 = 0.5$, and $\rho_2 = -0.5$.

Period	Output per Hour	Capital		Contribution from Labor			Efficiency	
	\hat{y}	$\bar{\beta}_b \hat{k}_b$	$\bar{\beta}_e \hat{k}_e$	$\bar{\beta}_s \hat{\ell}_s$	$\bar{\beta}_u \hat{\ell}_u$	$\bar{\beta}_e \hat{A}_e$	$\bar{\beta}_s \hat{A}_s$	$\bar{\beta}_u \hat{A}_u$
1950-2005	2.1	-0.1	0.1	0.6	-0.2	0.4	0.9	0.4
	(100)	(-6)	(4)	(29)	(-12)	(21)	(43)	(21)
1950-1970	2.9	-0.1	0.0	0.4	-0.2	0.3	0.9	1.5
	(100)	(-4)	(2)	(22)	(9)	(10)	(32)	(52)
1970-2005	1.6	0.1	0.1	0.7	-0.3	0.5	0.9	-0.2
	(100)	(7)	(7)	(34)	(-14)	(31)	(56)	(-14)

Notes: This table reports the growth accounting decomposition based on a higher elasticity of substitution between skilled and unskilled labor. \hat{x} represents the average annual growth rate of a variable x . Numbers in parentheses represent relative contributions in percentage.

Figure 5.b plots the time paths of efficiency indexes under $\rho_1 = 0.33$ and $\rho_2 = 0.25$ (i.e., capital and skill are gross substitute). Time trends of A_s and A_u are somewhat similar to those in Figures 2.b, although A_s has grown relatively faster in Figure 5.b: the average annual growth rate of A_s between 1950 and 2005 is 8.2 percent, whereas it is 6.9 percent in Figure 2.b. The evolution of A_k in Figure 5.b is considerably different from that in Figure 2.b: it has decreased at an average annual rate of 1.6 percent. The main conclusion in this exercise is that when there is one capital input, in which structure and equipment are perfect substitute with each other, the time paths of the efficiencies of capital and skilled labor depend on the elasticity of substitution between capital and skilled labor.¹⁹

How do these results differ from those in Caselli and Coleman (2002), who assume that $\rho_1 = \rho_2 = 0.25$? The time paths of A_s and A_u are similar to Caselli and Coleman's. The time path of A_k is different that in Caselli and Coleman (2002) who find that A_k rises from the mid 1960's to the mid 1980's. However, the differences between two plots stem from

skill-complementarity ($\rho_1 = 0.4$ and $\rho_2 = -0.5$) are similar to those under $\rho_1 = \rho_2 = 0.25$. My analysis suggests that the results related A_s in two specifications are very different.

¹⁹For the sake of brevity, I do not report the accounting results based on this production function. But they are available upon request.

differences in parameter ρ_1 and the time periods considered in two papers. For example, if I set $\rho_1 = 0.25$, I find that the efficiency of capital (slightly) rises from the mid 1960's to the late 1980's, as in Caselli and Coleman (2002).²⁰ But such a trend again disappears when the whole time period (1950-2005) is considered.

Another frequently used production function in accounting literature is Cobb-Douglas specification (e.g., Jones, 2002). Consider the following Cobb-Douglas specification:

$$Y_t = K_t^\alpha (A_t q_t N_t)^{1-\alpha},$$

where $K = K_b + K_e$ is the total capital stock, A is the total factor productivity (TFP), q denotes the average quality of each worker, and N_t is the number of (raw) labor hours employed in production (hence, $q_t N_t = L_{st} + L_{ut}$). By setting $\alpha = 1/3$, this equation implies that

$$\hat{y} = 0.5\hat{k} + \hat{q} + \hat{A},$$

where, as before, $y \equiv Y/N$, $k \equiv K/Y$, and \hat{x}_t represents the growth rate of variable x in year t .

By decomposing output per hour growth according to the above growth accounting equation, I find that the TFP contribution to growth in output per hour is about 87%, which is very close to the total contributions of efficiencies reported in Tables 1. Thus, in addressing the importance of factor inputs vs. efficiency, this simple Cobb-Douglas specification does a good job. However, there are two main problems with the Cobb-Douglas specification. First, it assumes that skilled and unskilled labor are perfectly substitutable, i.e. the elasticity of substitution between skilled and unskilled workers is infinity. The empirical labor literature, on the other hand, documents that it is well below infinity. Similarly, it does not differentiate different types of capital. Second, this approach is completely silent about the contributions of subcomponents to productivity growth. The analysis in this paper reveals that the components A_e , A_s , and A_u shows disparate trends.

²⁰The time path of A_k has not shown, but it is available upon request. Seemingly strong upward trend in A_k over the period 1965-1985 in Caselli and Coleman (2002) stems from their zooming of the vertical axis.

5 Conclusion

The relative supply of skilled labor has increased rapidly since the late 1960s, and the skill premium has increased sharply since 1980. It has been argued that this pattern is a result of the acceleration of skill-biased technical change. In this paper, using a production framework in which skilled and unskilled labor are imperfect substitutes, I analyze the time paths of skilled and unskilled labor efficiencies and investigate their implications for the economic growth and wage inequality in the US over the last half-century.

I find no evidence of an acceleration in the growth rate of skilled labor efficiency since the late 1970's to support the common view that there has been an acceleration in the new skilled-biased technologies. I also find a decline in the absolute level of the efficiency of unskilled labor since sometime around 1970, although the magnitude of the decline decreases as the elasticity of substitution between skilled and unskilled labor increases. Finally, I document that the evolution of the efficiency associated with capital equipment depends on the elasticity of substitution between capital equipment and skilled labor. These patterns imply that (i) the decline in unskilled labor efficiency also has an adverse effect on labor productivity growth; (ii) the dramatic rise in the U.S. skill premium over the last two decades has not only been driven by increases in the skilled labor efficiency, but also by declines in unskilled labor efficiency.

Data Appendix

The data on the labor supply and income are from the March Current Population Surveys (CPSs) for years between 1963 and 2006, Census IPUMS 1 percent extracts for years 1950 and 1960. Unfortunately, the data on employment benefits are not available. Thus, calculations of β_{jt} are based on the total income from wages and salaries. In this way, it is implicitly assumed that the fractions of total compensation paid as employer benefits to

skilled and unskilled workers are the same.²¹

Processing of March CPS Data

The March CPS is obtained from Unicon Research Corporation. The main advantage of using the data from Unicon is that Unicon has cleaned up all of the problems in the raw CPS files provided by the Census Bureau and recoded variables so that the surveys became more comparable across years. Constructions of the series for aggregate variables are accomplished in five steps:

Step 1: In each year, the data on employed people between 16 and 70 years old are divided into 72 groups characterized by sex, education, and experience.²² Education status, E , is divided into 4 categories: $E < 12$ (no high school diploma), $E = 12$ (high school graduate), $13 \leq E \leq 15$ (some college), and $E \geq 16$ (college graduate or more) to depict years of schooling.²³ Potential experience is calculated as $\text{Min}\{\text{age}-\text{years of schooling}-7, \text{age}-17\}$ following Katz and Murphy (1992), and experience status is divided into 9 categories (0–4, 5–9, ..., 35–39, 40+). Using the CPS sample weights, the fraction of total labor for each group in each year is calculated. These fractions are then multiplied by the annual employment data from the BEA to obtain the number of workers in each group.²⁴ Let $N_{\gamma t}$

²¹However, the Bureau of Labor Statistics reports employer benefits according to different occupational groups between 1986 and 2007 (<http://www.bls.gov/ncs/ect/home.htm#tables>). The percentage of total compensation paid to white-collar (blue-collar) workers has remained mostly stable around 27 (32) percent over this period, suggesting that the differences from employment benefits have negligible impacts on the results. I would like to thank Julie B. Cullen for bringing this data source to my attention.

²²This taxonomy is the same as in Autor et al. (2008). When aggregating labor inputs, Autor et al. divide potential experience status into finer groups than I do. However, in that case several groups remained empty. To be more consistent across all groups, I consider a higher level of aggregation. In the previous version of this paper, I imputed the data for an empty group by assigning the mean of a more aggregated group (following Autor et al. (2008)), but such approach yielded very similar results.

²³Commencing in 1992, the Bureau of the Census changed the emphasis of its educational attainment question from years of education to degree receipt. To obtain a comparable educational-attainment data across years, the classification proposed by Jaeger (1997) is followed. Specifically, high school dropouts are those with fewer than 12 years of schooling; high school graduates are those with either 12 years of education and/or a high school diploma; some college are those attending some college or holding an associate's degree; and college plus are those with a bachelor's degree or higher.

²⁴The annual employment numbers reported by the BEA are usually close to the number of workers obtained from the CPSs. In some years, however, the total employment data obtained from the CPSs fluctuate substantially from the adjacent years. Therefore, individual cells are adjusted according to the

represents the total number of workers in group γ in year t .

Step 2: Self-employed workers and workers with imputed earnings are excluded.²⁵ Two adjustments for topcoded earnings are also made. First, following Autor et al. (2008) income of workers with top coded earnings are imputed by multiplying the annual topcode amount by 1.5. Second, starting in 1996, topcoded earnings values are assigned the mean of all topcoded earners. In these cases, we simply reassign the topcoded values to all observations and again multiply by 1.5.²⁶ Earnings are deflated using the Personal Consumption Expenditure (PCE) deflator from the BEA.

Step 3: Hourly wages are formed by dividing annual incomes by imputed measures of hours worked during the previous year. Imputed hours are formed by multiplying *imputed* weeks by hours worked last week. An imputed measure of weeks worked is used since the exact number of weeks worked is not available in the CPS prior to 1976. Following Katz and Murphy (1992), the sample for 1976-2005 is divided into groups defined by the weeks worked brackets used in the earlier surveys and sex. The means of weeks worked for these groups from the 1976-2005 surveys are used as estimates of weeks worked for individuals in the corresponding groups.²⁷

Hours worked last week are used, since the data on hours worked last year are not available in the CPS prior to 1976. In computing the group labor hour, first the individuals are sorted into part-time and full-time status using the census part-time, full-time flag. Full-time is defined as those who work at least 35 hours per week. Then, in each group, for

BEA employment data.

²⁵The sample does not include allocated earnings observations due to the fact that the imputation procedures changed between 1975 and 1976. To exclude imputed wages, following Autor et al. (2008), family earnings allocation flags (1966-1975) and individual earnings allocation flags (1976 onward) are used.

²⁶Unassigned topcoded values are available in the surveys. For example, for the secondary earning value, the topcoded maximum is set at 99,999 from 1988 to 1995, falls to 25,000 for 1996 through 2002, and rises to 35,000 in 2003 through 2006.

²⁷To be consistent over time, unlike Katz and Murphy (1992) who use the estimated weeks only for the earlier surveys, estimated weeks are used in all years. Imputations based on the 72-group classification yielded similar estimates.

full-time workers who reported less than 35 hours per week, it is assumed that their weekly supply of hours is equal to that of the average full-time worker belonging to the same group. The same method is used to calculate the weekly supply of hours by part-time workers who reported either zero hours or worked more than 35 during the last week.²⁸ In all such calculations CPSs weights are used. Following Autor et al. (2008), the full-time workers with real hourly wage below \$2.6 (which roughly corresponds \$112 per week) are dropped. Similarly, the bottom 1 percent of hourly wages of part-time workers are also dropped. In each year, the maximum hourly wage of part-time workers is also limited to the maximum annual income of full-time workers divided by 1,750 (35 hours per week and 50 weeks per year). This correction prevents part-time workers from having a higher feasible hourly wage than full-time workers (see Autor et al. (2008)). These adjustments are made to reduce possible measurement errors stemming from the imputed weeks/hours, but the results are not sensitive to such corrections. The average annual hours of each group is then adjusted by a fixed factor so that the average annual hours worked per person is the same as that reported by the BEA.²⁹

Step 4: Let W_{it} and ℓ_{it} represent individual i 's annual income and total labor input in year t , respectively. The corresponding hourly wage rate, w_{it} , is given by $w_{it} = W_{it}/\ell_{it}$. For the group γ , the average labor input and the average wage rate are then computed as

$$\ell_{\gamma t} = \frac{\sum_{i \in \gamma} \ell_{it} \mu_{it}}{\sum_{i \in \gamma} \mu_{it}}, \quad w_{\gamma t} = \frac{\sum_{i \in \gamma} w_{it} \mu_{it}}{\sum_{i \in \gamma} \mu_{it}},$$

where μ_{it} is individual i 's CPS sampling weight.

Total annual income of group γ in year t , $W_{\gamma t}$, is then given by $W_{\gamma t} = w_{\gamma t} \ell_{\gamma t} N_{\gamma t}$, where

²⁸The part-time workers constitute relatively small fraction of employed labor force, less than 20% of the sample.

²⁹The BEA also reports total hours worked from 1947 to 2006. Using the employment data, it is easy to derive the average annual hours worked by each person. Compared to these data, the average annual hours data obtained from the CPSs show some deviations. To correct these deviations, I multiplied each group average hour by the ratio of the BEA average annual hours per worker to that obtained from the CPS data. Notice that such an adjustment does not affect relative wages and relative labor supplies, and hence, does not affect their time trends. Analysis without such an adjustment yields similar results to those reported in the text.

$N_{\gamma t}$ is the total number of people in group γ . Thus, the total compensation paid to the skilled workers, W_{st} , is given by $W_{st} = \sum_{\gamma \in \Gamma_s} W_{\gamma t}$, where Γ_s denotes the set of skilled groups. Similarly, the total compensation paid to the unskilled workers, W_{ut} , is given by $W_{ut} = \sum_{\gamma \in \Gamma_u} W_{\gamma t}$.

Step 5: The aggregation of labor inputs into skilled and unskilled classes is achieved as follows. Groups within a class are assumed to be perfect substitutes, and as indicated in the main text, group relative wages are used as weights for the aggregation. For each group in each year, a relative wage measure is constructed by dividing each group's average hourly wage by the average hourly wage of the group which contains white males who have less than 12 years of schooling and less than 5 years of experience in the contemporaneous year.³⁰ The relative quality index measure for each group, q_γ , is computed as the arithmetic mean of the relative wage measures in that group over 1950 to 2005. Then the total quality-adjusted labor input in each class is given by

$$L_{jt} = \sum_{\gamma \in \Gamma_j} q_\gamma \ell_{\gamma t} N_{\gamma t}, \quad j = s, u.$$

The corresponding *quality-adjusted* average wage rate for each class is calculated as $w_{jt} = W_{jt}/L_{jt}$, as in Krusell et al. (2000).

Processing of Census Data

The Census IPUMS surveys are available at www.ipums.org. The processing of census data is very similar to that of the CPS; the data on employed people (who are currently employed) between 16 and 70 years old are divided into 72 groups characterized by sex, education, and experience. Following Autor et al. (2008), (i) individuals who are self-employed, (ii) worked in unpaid family work, and (iii) who did not live in correctional institutions, mental institutions, or other non-institutional group quarters are excluded from the sample. Top-coded earnings are multiplied by 1.5 and the earning numbers are deflated using the PCE.

³⁰This choice of the base group is innocuous. For example, Katz and Murphy (1992) index each group's wage to the wages for a fixed bundle of workers.

Imputed weeks from the previous section are used. For the 1960 sample, an imputed measure of hours worked last week is used since the *exact* number of hours worked is not available in that year. To impute hours, the census sample for 1950 is divided into groups defined by the hours worked brackets used in the 1960 survey and sex. The means of hours worked for these groups in the 1950 survey are used as estimates of hours worked for individuals in the corresponding groups.

Imputed hours are formed by multiplying imputed weeks by hours worked last week. Unfortunately, there is no worker type flag to distinguish who is a full-time worker. As a result, all observations with real hourly earnings below \$2 dollar are dropped. The maximum hourly wage of part-time workers is limited to the maximum annual income of workers divided by 1,750 (35 hours per week and 50 weeks per year), following Autor et al. (2008).

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