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Abstract

The wage premium for high-skilled workers in the United States, measured as the ratio of the 90th-to-10th percentiles from the wage distribution, increased by 20 percent from the 1970s to the late 1980s. A large literature has emerged to explain this phenomenon. A leading explanation is that skill-biased technological change (SBTC) increased the demand for skilled labor relative to unskilled labor. In a calibrated vintage capital model with heterogenous labor, this paper examines whether SBTC is likely to have been a major factor in driving up the wage premium. Our results suggest that the contribution of SBTC is very small, accounting for about 1/20th of the observed increase. By contrast, a gradual and very modest shift in the distribution of human capital across workers can easily account for the large observed increase in wage inequality.

Keywords: Wage premium, skill-biased technical change, vintage capital, heterogenous labor supply

JEL Codes: J24, E24.

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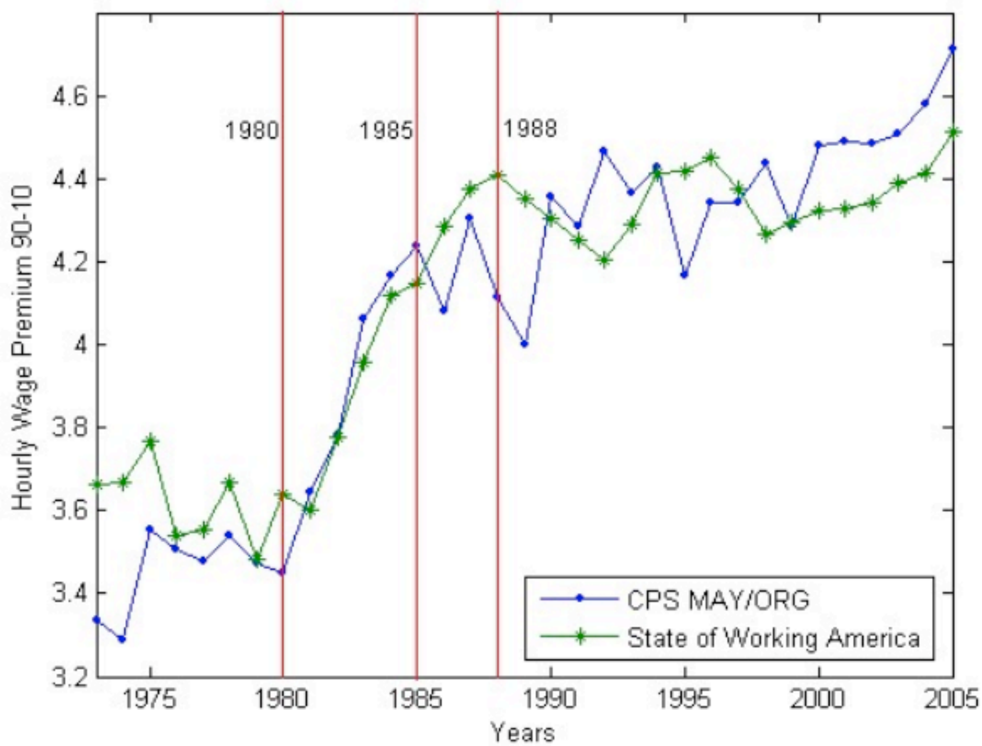
1 Introduction

The wage premium in the United States, which can be defined as the ratio of the wages paid to high-skilled workers relative to wages paid to low-skilled workers, underwent dramatic changes during the 1980s. Figure 1 displays the 90-10 wage premium (wage ratio of the 90th percentile to the 10th percentile) for hourly workers using two separate data sources: the CPS May/ORG and the State of Working America. From the figure, the data can be be broken down into three separate periods, characterized as low, transition, and high. Both data sources suggest a low wage premium period from 1973 to 1980, with the 90-10 wage premium approximately equal to 3.45 and 3.62 respectively. The next few years can be regarded as a transition period. The CPS May/ORG suggests this period extended from 1981 to 1985 while the State of Working America suggests it extended from 1981 to 1988, with the average 90-10 wage premium equal to 3.98 and 4.08, respectively. For the high wage premium period, CPS May/ORG indicates a period from 1986 to 2005 and State of America from 1989 to 2005, with the average 90-10 wage premium equal to 4.36 and 4.35, respectively.

Over the past twenty years, a large literature has attempted to explain this increase in the wage premium. Among the major explanations for this change are shifts in the supply of and demand for skills, the increased volume of international trade and the erosion of labor market institutions – including labor unions and the minimum wage – that protected the earnings of low/medium-wage workers. Perhaps the most prominent of these is the one that involves Skill-Biased Technological Change (SBTC hereafter). SBTC induces a shift in production technology that favors skilled over unskilled labor, essentially increasing the relative productivity of skilled labor and, therefore, its relative demand.

Katz and Murphy (1992) argue that a simple supply and demand framework can explain the dynamics of the wage premium: "A smooth secular increase in the relative demand for college graduates combined with the observed fluctuations in the rate of growth of relative supply could potentially explain the movements in the college wage



NOTE: The 90-10 wage premium is the ratio of the 90th to the 10th percentiles of hourly wages based on: CPS data in May/ORG [see Autor, Katz, and Kearney (2008) for details] and the State of Working America 2006-2007, Table 3.4 using CPS wage data.

Figure 1: 90-10 Wage Premium

premium from 1962 to 1987." They suggest that the wage premium dropped during the 1970s because the supply of skilled workers exceeded demand in the baby boom period. In the 1980s, the wage premium increased dramatically, possibly due to an acceleration of skill-biased technological change that increased the demand for skilled labor at a faster pace than the increase in the supply of skilled labor during this period.

A large literature has emerged that supports SBTC as the principal factor contributing to the rise of wage inequality. Bound and Johnson (1992) examine changes in wage structure in the 1980s in the United States and conclude that the major cause may have been SBTC in production technology. Berman, Bound and Griliches (1994) argue that SBTC accounts for a large fraction of the skill upgrading which they have observed in manufacturing. They conclude that SBTC has been an important source of the outward shift in the demand for educated/skilled labor, and constitutes the main reason for the increase in the wage premium.

Krueger (1993) shows that workers who use computers on their job earn roughly a 10-15 percent higher wage rate, which suggests a strong impact of computers on the structure of wages. Autor, Katz, and Krueger (1998) examine the conribution of SBTC, as measured by computerization, to the widening of U.S. educational wage differentials in the 1980s. They show that the rate of skill upgrading has been greater in more computer-intensive industries.

Krusell, Ohanian, Rios-Rull, and Violante (KORV 2000) focus on an explanation for the wage premium associated with investment-specific technological change and capital-skill complementarity in production. They claim that the growth in the stock of capital equipment will increase the marginal product of skilled labor and hence raise its relative demand. In other words, the economy's ever-improving technology requires an ever more highly skilled workforce, and this pushes up the wages of high-skilled workers relative to low-skilled workers.

Acemoglu (2003) claims that international trade induced SBTC. The trade explanation suggests that the U.S. skill premium increased because trade with skill-scarce less-developed countries (LDCs) raised the demand for skilled Americans.[1] The opening of trade can induce skill-biased technical change, resulting in a rise in the relative prices of skill-intensive workers in the United States—without the usual intervening mechanism of standard trade models.

Other research has attempted to provide evidence suggesting that both supply-demand shifts and SBTC are weak explanations for the changes in wage inequality. Card and DiNardo (2002) review the evidence for the SBTC hypothesis, focusing on the implications of SBTC for overall wage inequality and for changes in wage differentials between groups. They show that the evidence linking wage inequality to SBTC is surprisingly weak, and that SBTC fails to explain the evolution of the other dimensions of wage inequality, including gender and racial wage gaps and the age gradient in the return to education. Lemieux (2006) points out that residual inequality actually declined in periods other than the 1980s. For technological change to be a key driver of the wage premium, it is necessary to argue that while technological change was biased in favor of skilled workers during the 1980s, it was biased in favor of unskilled workers at other times.

Using a semi-parametric estimation procedure. DiNardo, Fortin, and Lemieux (1996) find quantitative evidence that de-unionization and supply-demand shocks were important factors in explaining the rise in wage inequality from 1979 to 1988. In addition, the decline in the real value of the minimum wage explains a substantial role. They conclude that labor market institutions are as important as supply-demand considerations in explaining changes in the U.S. wage distribution from 1979 to 1988. Acemoglu, Aghion, and Violante (2001) also show that de-unionization amplifies the direct effect of skill-biased technical change by removing the wage compression imposed by unions.

Lemieux (2006) concludes that the rise of residual inequality in the 1980s was an episodic event accounted for by the declining value of the minimum wage and

[1] Others have suugested that the increased volume of international trade between skill-scarce, less-developed countries and skill-abundant, developed economies may have put downward pressure on the wages of low-skilled workers in the United States. [See Wood (1995) and Leamer (1996).]

that an apparent increase since the mid-1980s reflects the mechanical effects of the changing composition of the labor force (associated with increases in education and experience). But the matter is far from settled. Autor, Katz, and Kearney (2008) argue that there is limited support for "revisionist" claims that the increase in U.S. wage inequality since 1980 was "episodic," and that fluctuations in the real minimum wage do not constitute a plausible explanation. Instead, they find evidence in support of the view that increases in the relative demand for skills – attributable to SBTC – and a sharp deceleration in the supply of college workers in the 1980s do an excellent job of capturing the evolution of the college/high school wage premium.

This paper takes a different approach toward accounting for the observed increase in wage inequality in the United States. It relies on a calibrated vintage capital model with a heterogenous workforce in which economic growth results from both disembodied and embodied technological progress.[2] Disembodied technological change induces productivity improvements in all production processes symmetrically. Embodied technological progress introduces productivity gains that are vintage-specific and therefore have the potential to induce a greater wage premium as the demand for more skilled workers to operate the more recent technology increases. It seems to us that this model provides a natural framework for studying the issues at hand.

A key feature of the model is the heterogeneity of the workforce and the assignment of workers to production processes employing certain vintages of capital. The workforce is characterized by a skill distribution that is calibrated to match the 90-10 wage distribution. A matching rule, whereby the "best workers" are matched with the latest technology, is assumed.[3] Importantly, we relax a common assumption in the SBTC literature (see, for example, KORV), which is that there is no substitution between high- and low-skilled workers in production. Consider, for example, what

[2]This model is developed in Marquis and Trehan (2007) and examined in more detail in Tantivong (2009), from which the arguments in this paper are taken.

[3]This matching rule is consistent with the rule that Jovanovic (1998) identifies as being both plausible and empirically well-founded. In this model, it also results in the most efficient labor allocation. For example, any other mix of labor and capital lowers output, holding labor and capital fixed.

happens when an increase in embodied technological progress raises the productivity of workers associated with the latest technology and thereby increases the demand for highly skilled workers. In our model, this greater demand is met by shifting relatively less-skilled workers into the production process employing the latest technology. This shift has the effect of mitigating the wage premium.

Also unlike the typical SBTC model, our model allows for new technology to eventually permeate the entire workforce, eventually benefitting all workers. It seems to us that making use of new technologies, while it may require a new and different set of skills, does not necessarily require skills that are are more difficult to master than the skills required to operate older technologies. The technology eventually filters throughout the workplace and benefits all workers.[4] This argument is consistent with Aghion's (2002) notion of Major Technological Change, and particularly the new General Purpose Technologies in communication and information that have recently diffused throughout the workforce of industrialized economies.

The model is used first to examine whether a secular shift from disembodied to embodied technological progress (that is consistent with the overall rate of economic growth) is a plausible explanation for the sizable increase in the 90-10 wage premium that occurred in the United States during the 1980s. The results suggest that it is not, in that the increase in the wage premium predicted by the model is much too modest, approximately 1/20th of that observed in the data. The paper then turns to the supply side of the labor market and asks whether supply-driven factors could plausibly account for the widening wage premium. The results indicate that they are indeed good candidates. Only a gradual and modest shift in the skill distribution of the workforce easily produces a steepening of the wage gradient across worker categories sufficient to account for the observed secular change in the wage premium.

The plan of the paper is as follows. Section 2 describes the theoretical model that incorporates a heterogeneous workforce into a vintage capital model and derives the

[4]The technology of bar codes used at checkout in retail stores is a good example of productivity-enhancing technology that does note require sophisticated training to employ.

equilibrium balanced growth path. Section 3 presents the calibration of the model. Section 4 shows that a shift in the source of technological progress towards embodied technology leads to only a modest increase in the 90-10 wage premium, one that is far below what was observed in the U.S. during the 1980s. Section 5 demonstrates how only gradual and modest shifts in the skill distribution of the workforce are required to account for the observed changes in wage inequality. The last section summarizes the findings and suggests directions for future research.

2 A Vintage Capital Model with Heterogenous Labor

The theoretical model contains two sources of growth. The first source is improvements in disembodied technology, which affects all production processes symmetrically. The second source is improvements in embodied technology, which differentially affects productivity across the production processes by determining the quality of the newest vintage. The number of vintages in the economy is assumed to be fixed, and enforced by an exogenous scrappage rule. After the latest embodied technology is introduced, the oldest vintage of capital is sold for scrap. This results in a schedule of prices for capital goods that declines with vintage.

2.1 Production with Vintage Capital

Output in the economy can be produced from a number of production processes that are distinctly identified by the vintage of capital that they utilize. Each production process is affected by the same economy-wide disembodied technology, denoted μ_t. We denote the vintage of capital employed by each production process by the index $j = 1, ..., T$, where T is the number of vintages in the economy. The newest vintage of capital in production at date t is represented by K_t^1 and the oldest by K_t^T. The production function is linear, Cobb-Douglas across all production processes given by:

$$F(K_t^J, H_t^j; \mu_t, A_{t-1}) = \mu_t \sum_{t=0}^{T} (K_t^j)^\alpha (A_{t-j} H^{j_t})^{1-\alpha}, \;\; \alpha \in (0,1), \;\; j = 1, ..., T \qquad (1)$$

where A_{t-j} is the vintage-specific level of embodied technology that is matched with the total human capital, H_t^J, or quality-adjusted labor utilized in vintage j at date t. Note that fewer high-skilled workers are required to attain a given level of H_t^j than would be the case for lower skilled workers. Therefore, the total hours worked assigned to any particular production process depends on both the embodied technological progress and the average skill level of a particular group of workers, whose composition is endogenously determined.

The two sources of long-run productivity growth are the gross growth rate of embodied technology, represented by γ_t:

$$\gamma_{t-j} = \left(\frac{A_{t-j}}{A_{t-j-1}}\right), \;\; j = 1, ..., T \qquad (2)$$

and the gross growth rate of disembodied technology, g_t:

$$g_t = \left(\frac{\mu_t}{\mu_{t-1}}\right) \qquad (3)$$

To render the model stationary, a useful normalization was chosen, which we now describe. The normalized capital stocks are denoted:

$$\tilde{K}_t^j = \left(\frac{K_t^j}{\Omega_{t-j}}\right), \;\; j = 1, ..., T \qquad (4)$$

where the newest vintage of capital is normalized on the current level of disembodied technology and the level of embodied technology associated with the oldest vintage of capital used in current production, or:

$$\Omega_{t-1} = \mu_t^{\frac{1}{1-\alpha}} A_{t-T} \qquad (5)$$

and the general form for any given vintage j is:

$$\Omega_{t-j} = \mu_{t-j+1}^{\frac{1}{1-\alpha}} A_{t-T-j+1} \tag{6}$$

Hence, the normalized production function is given by:

$$\tilde{F}(K_t^j, J_t^j; G_{t-i}\Gamma_{t-j}) = \sum_{t=1}^{T} \left(\frac{\tilde{K}_t^j}{\Pi_{t=0}^{j-2} G_{t-i}} \right)^{\alpha} (\Gamma_t^i H_t^j)^{1-\alpha}, \ \alpha \in (0,1), \ j = 1, ..., T \tag{7}$$

where

$$\tilde{F} = \left(\frac{F}{\Omega_{t-1}} \right) \tag{8}$$

and

$$G_{t-i} = \left(\frac{\Omega_{t-i-1}}{\Omega_{t-i-2}} \right) \tag{9}$$

with $\Pi_{i=0}^{-1} G_{t-i} \equiv 1$. The relative level of embodied technology between the jth vintage of capital and the oldest (Tth) vintage is given by:

$$\Gamma_t^j = \left(\frac{A_{t-j}}{A_{t-T}} \right), \ j = 1, ..., T \tag{10}$$

Note that:

$$\Gamma_t^1 > \Gamma_t^2 > ... > \Gamma_t^T = 1 \tag{11}$$

where Γ_t^j can be interpreted as the "quality gradient" in capital across vintages. The more rapid is the pace of embodied technological progress, the steeper is the quality gradient.

Hence the gross growth rate of the economy at date T is represented as G_t, which reflects both disembodied and embodied technological progress:

$$G_t = g_t^{\frac{1}{1-\alpha}} \gamma_{t-T} \tag{12}$$

2.2 Workforce Heterogeneity

There are P workers in the economy. The human capital of the workers in the economy is distributed along the unit interval that is indexed by x, with $x \in [0, 1]$. The human capital of each worker with index x is denoted by $h(x)$ where the most highly skilled workers have an index of $x = 0$ and a human capital level of $h(0)$, and the least-skilled workers have an index of $x = 1$ and a human capital level of $h(1)$.

Households face a time constraint for their labor-leisure decision. For each worker, the time constraint is $z_t + l_t \leq 1$, where z_t is the fraction of time devoted to labor and l_t is the fraction of time devoted to leisure. The household's total leisure time for all workers is given by $L_t = Pl_t$. Hence, the total time allocated to labor is:

$$Pz_t = P - L_t \tag{13}$$

The total amount of human capital that is allocated to vintage j is given by:

$$H_t^j = Pz_t \int_{x^{j-1}}^{x_t^j} h(x)dx = Pz_t\chi(x)[\chi(x_t^j) - \chi(x_t^{j-1})], \ j = 1, ..., T \tag{14}$$

where $z_t\chi(x)$ is the cumulative distribution of human capital per capita employed at date t. The total number of hours worked by workers assigned to capital of vintage j is given by:

$$N_t^j = Pz_t \int_{x^{j-1}}^{x_t^j} dx = Pz_t[x_t^j - x_t^{j-1}], \ j = 1, ..., T \tag{15}$$

2.3 Household Optimization

Households own the capital goods whose prices are determined as in Lucas (1978). The representative household selects contingent group employment decision rules by partitioning x into T worker groups of contiguous skill levels, denoted $\hat{x}_t^j = x_t^j - x_t^{j-1}, \ j = 1, ..., T$ that determine the amount of quality-adjusted labor that is being offered to the firm. The precise "partitioning" of the workforce is an equilibrium outcome with the firms setting demand schedules for human capital assigned to each vintage according to the "matching rule" of "best workers" with the "best machines."[5] The household also makes consumption-saving, labor-leisure, and capital asset portfolio allocation decisions. The household's optimization problem is:

$$\max_{\{c_t, L_t, \hat{x}_t^j, K_{t+1}^j\}} \sum_{t=0}^{\infty} \beta^t U(c_t, L_t), \;\; j = 1, ..., T \tag{16}$$

where c_t is the household's consumption, $\{K_{j+1}^{j_t}\}^T$ is the household's capital holdings whose values are given at date $t = 0$ when the optimization is conducted.

The household's budget constraint is:

$$c_t + K_{t+1}^1 + \sum_{j=1}^{T-1} p_t^j K_{t+1}^{j+1} \leq \sum_{j=1}^{T} R_t^j K_t^j + \sum_{j=1}^{T} W_t^j H_t^j + \sum_{j=1}^{T} p_t^j (1-\delta) K_t^j, \;\; \delta \in (0,1) \tag{17}$$

To purchase consumption and investment goods, the household combines its capital income (where R_t^j is the rental rate on a unit of the jth vintage of capital), its labor income (where W_t^j is the wage rate per unit of quality-adjusted labor—or human capital—assigned to the jth production process) and the revenue from the sale of capital holdings (where p_t^j is the market price of the jth vintage of capital at date t, and δ is the depreciation rate). Note that investment in the newest vintage of capital, K_{t+1}^1, will be rented to the firm in period $t+1$.

The household's labor supply decisions are further constrained by its total available human capital and the matching rule, such that:

$$H_t^j = P z_t [\chi(x_t^j) - \chi(x_t^{j-1})], \;\; j = 1, ..., T \tag{18}$$

and

$$\sum_{j=1}^{T} \hat{x}_t^j = \sum_{j=1}^{T} [x_t^j - x_t^{j-1}] = 1 \tag{19}$$

The household also faces a time resource constraint:

[5] As noted earlier (fn 3), this yields the optimal labor allocation.

$$z_t + \frac{L_t}{P} \leq 1 \tag{20}$$

The household's problem is normalized with Ω_{t-1}, where normalized consumption and normalized wages are defined as $\tilde{c}_t = \left(\frac{c_t}{\Omega_{t-1}}\right)$ and $\tilde{w}_t^j = \left(\frac{W_t^j}{\Omega_{t-1}}\right)$. The Euler equations for the consumption-savings/porfolio allocation decisions are:

$$\beta\Big\{\Big(\frac{U_{\tilde{c}_{t+1}}}{U_{\tilde{c}_t}}\Big)\Big[\frac{R_{t+1}^{j+1} + p_{t+1}^{j+1}(1-\delta)}{G_{t+1}p_t^j}\Big]\Big\} = 1,\ p_t^0 = 1,\ j = 0, ..., (T-1) \tag{21}$$

These Euler equations take the form of asset pricing equations for the various vintages of capital. There is no investment in vintage T, since it is scrapped at the end of the period. The wage rate paid per unit of human capital (quality-adjusted labor) is the same across all worker groups, that is:

$$\tilde{w}_t^j = \tilde{w}_t^{j+1},\ j = 1, ..., T \tag{22}$$

The Euler equation for the labor-leisure decision for all workers is:

$$U_{\tilde{c}_t} \sum_{j=1}^{T} H_t^j \tilde{w}_t^j = z_t P U_{Lt} \tag{23}$$

2.4 Firm's Optimization

The firm is assumed to be competitive in factor and product markets. It hires quality-adjusted units of labor and rents physical capital of all vintages from households. The firm matches the most highly skilled workers with the latest vintage capital and pays the workers who are assigned to work with the same vintage capital the same wage. The firm chooses factor inputs to maximize profits period-by-period:

$$\max_{K^j, H_t^j} \Big[\mu_t \sum_{j=1}^{T} (K_t^j)^{\alpha}(A_{t-j}H_t^j)^{1-\alpha} - \sum_{j=1}^{T} R_t^j K_t^j - \sum_{j=1}^{T} W_t^j H_t^j\Big],\ j = 1, ..., T \tag{24}$$

The first-order condition for the firm's problem set the rental rate on capital and the wage rate on labor equal to their marginal products:

$$\alpha\Big(\frac{\tilde{K}_t^j}{H_t^j}\Big)^{(\alpha-1)}\Big(\Pi_{i=0}^{j-2}G_{t-i}\Big)^{(1-\alpha)}(\Gamma_t^j)^{(1-\alpha)} = R_t^j,\ j=1,...,T \tag{25}$$

$$(1-\alpha)\Big(\frac{\tilde{K}_t^j}{H_t^j}\Big)^{\alpha}\Big(\Pi_{i=0}^{j-2}G_{t-i}\Big)^{-\alpha}(\Gamma_t^j)^{(1-\alpha)} = \tilde{w}_t^j,\ j=1,...,T \tag{26}$$

Note that from the matching rule, the firm will wish to allocate more human capital to vintages that possess a higher level of embodied technology. This effect is more pronounced as the quality gradient steepens.

2.5 Equilibrium

Equilibrium in the goods market consists of transforming output goods along with the scrapped capital of vintage T—the sum of which is defined as normalized output and denoted $\tilde{y}_t$—into consumption and new investment, or

$$\tilde{c}_t + \tilde{i}_t = \tilde{y}_t = \sum_{j=1}^{T}\Big(\frac{\tilde{K}_t^j}{\Pi_{i=0}^{j-2}G_{t-i}}\Big)^{\alpha}(\Gamma_t^j H_t^j)^{1-\alpha} + p_t^T(1-\delta)\Big(\frac{\tilde{K}_t^T}{\Pi_{i=0}^{T-2}G_{t-i}}\Big) \tag{27}$$

where $\tilde{i}_t = G_{t+1}\tilde{K}_{t+1}^j$ is normalized investment. Given the exogenous scrappage rule, the undepreciated portion of the oldest vintage of capital is sold at the end of the period for a unit price of p_t^T, which is a linear projection of the equilibrium schedule of prices for vintages $T-1$ and $T-2$:

$$\frac{p_t^T}{p_t^{T-1}} = \frac{p^{T-1}}{p_t^{T-2}} \tag{28}$$

The evolution of the normalized stock of capital is given by:

$$\tilde{K}_{t+1}^{j+1} = (1-\delta)\tilde{K}_t^J \tag{29}$$

3 Calibration Issues

Since this paper is interested in examining the increase in the wage premium that occurred during the 1980s (see Figure 1 and Table 1), the exercises described in the next section are based on a benchmark model calibrated to match the initial "low level" 90-10 wage premium that prevailed over the 1973 to 1980 period.

Table 1: The Average 90-10 Wage Premium

Periods	CPS May/ORG	State of Working America
Low Level	3.4542	3.6319
Transition	3.9787	4.0836
High Level	4.3610	4.3483

NOTE: The time periods for the CPS May/ORG data are 1973-1980 (Low), 1981-1985 (Transition), and 1986-2005 (High). The time periods for the State of Working America data are 1973-1980 (Low), 1981-1988 (Transition), and 1989-2005 (High).

This calibration takes as given the stock of human capital in the economy based on the estimated distribution of Abowd, Legermann, and McKinney (2002). Their estimates are based on the Longitudinal Employer-Household Dynamics (LEHD) Program data for 1992.[6] An exponential distribution function that fits their data well is estimated to be:

$$h(x) = S_0 e^{\phi(1-x)}, \ S_0, \phi > 0 \tag{30}$$

with the values of $S_0 = 8.92$ and $\phi = 2.187$.[7] Based on this distribution, the total

[6]These data cover California, Illinois, Michigan, and North Carolina for the first quarter, and include over 400,000 observations. See Abowd, Lengermann, and McKinney (2002), Table 9.

[7]The empirical model was estimated to be $Lhc = 9.21 + 0.0219Pe$, where Lhc denotes the log of the dollar value of human capital and Pe denotes the percentile of the human capital distribution. The equation had an adjusted-R^2 of 0.98.

value of human capital in the economy was then computed.

Holding the stock of human capital in the economy fixed, the values of S_0 and ϕ required to match the "low level" 90-10 wage premium were then estimated using the CPS May/ORG and State of Working America data. These values are reported, along with the other parameter values for the calibration, in Table 2. The remainder of the calibration procedure is described below.

Table 2: Benchmark Parameters

Parameters	Benchmark Values	Parameters	Benchmark Values
α	0.33	S_0^{CPS}	12.6505
β	0.96	ϕ^{CPS}	1.6500
δ	0.083	S_0^{State}	12.1272
η	2.4847	ϕ^{State}	1.7167
α	0.33	$\bar{G}$	1.025

NOTE: The superscript *CPS* represents the values calculated by using the CPS May/ORG data. The superscript *State* represents values calculated by using State of Working America 2006-07 data. S_0 and ϕ are calculated at the low level steady-state of 90-10 wage premium.

A semi-log utility function is assumed that is consistent with extensive-margin adjustments in the labor market as in Rogerson (1988):

$$U(\tilde{c}_t, L_t; \Omega_{t-1}) = \ln(\Omega_{t-1}\tilde{c}_t) + \eta L_t, \;\; \eta > 0 \tag{31}$$

The number of vintages of capital, T, is set to 12, corresponding to an annual depreciation rate of $\delta = 0.083$. For this calibration, there are 75 endogenous variables: $H^j, x^j, L, z, p^j, r^j, \tilde{c}, \tilde{K}^j, \tilde{w}^j,\;\; j = 1, ..., 12$, where the net real rental rate on the jth vintage of capital is $r^j = R^j - \delta$; 13 exogenous variables: $\gamma_{t-j}, G,\;\; j = 1, ..., 12$; and 7 parameters: $S_0, \phi, \beta, \delta, \eta, \alpha, P$. The selection of S_0, ϕ, and δ are described above.

Capital's share of income is set to $\alpha = 0.33$. The population of workers is an exogenous scale variable in the model set to 100. The breakdown of the sources of growth between disembodied and embodied technology is based on the results of Greenwood, Hercowitz, and Krusell (1997), Gilchrist and Williams (2000), and Wilson (2001) who estimate the contribution of embodied technological progress to lie within the range of 50 to 70 percent. Therefore, for this calibration, the annualized gross growth rate of the economy is set to $G = 1.025$, 60 percent of which is attributed to embodied technological progress, or $\gamma_{t-j} = 1.015$, $j = 1, ..., 12$. The discount factor is set to $\beta = 0.96$ for the annual calibration. A 40-hour workweek is assumed, implying a value for $z = 0.36$, which corresponds to a preference parameter in the utility function of $\eta = 2.4847$. The average net rental rate, $\bar{r}^j$, is 6.85 percent, or 7.32 percent when weighted by the capital stock.[8] These numbers are broadly consistent with the long-run average returns reported in Mehra and Prescott (2008).

4 Comparative Statics Results

This section conducts comparative statics exercises to examine whether an increase in the pace of embodied technological progress can lead to shifts in the relative demand for skilled labor large enough to account for the observed increase in the wage premium. Contrary to the argument put forward in the SBTC literature, we find that this channel does not take us very far. More specifically, an increase in the pace of embodied technological progress can account for no more than 1/20th of the observed 20 percent increase in the 90-10 wage premium. An alternative explanation–changes in the skill distribution of the workforce–turns out to be more promising. Very modest shifts in labor supply, with relatively fewer high-skilled workers and relatively more low-skilled workers, can easily account for the observed increase in wage inequality.

[8] The average real net rental rate computed by weighting capital is calculated by averaging the total rental rate of all vintages $(\frac{\sum R^j K^j}{\sum K^j})$.

4.1 Demand-Driven Factors

In the theoretical model, technological progress enhances labor productivity and can increase the wage rate of workers. Those workers assigned to the same vintage of capital receive the same wage, while those assigned to newer vintages of capital can receive a boost to their marginal product of labor associated with the latest technology. Therefore, workers who are matched with the later vintages of capital benefit the most from a steepening of quality gradient of capital, which results from a secular shift in the source of economic growth from disembodied to embodied technology. This tends to raise the wage premium. However, accompanying a steepening of the quality gradient of capital is an increase in the number of workers matched with newer vintages. This reallocation of labor (ceteris paribus) tends to reduce the wages at the high end of the wage distribution, while increasing the wages at the low end, thus tending to lower the wage premium.

In this first exercise, we compute the impact on the 90-10 wage premium of a shift in the source of economic growth from the benchmark 60 percent embodied-40 percent disembodied technology to a 100 percent embodied technology. On balance, the offsetting effects of a steeper quality gradient of capital described above weigh in favor of an increase in the wage premium. However, this increase is small. Referring to Table 3, the 90-10 wage premium is seen to increase by only about one percent from the calibrated low level to the its new steady state, whether we use the CPS May/ORG data or the State of Working America data for the calibration. By contrast, the data indicate that the wage premium actually went up by more than 20 percent from the low level to the high level period.[9]

We show a second, extreme case, where we assume that the original technology was 0 percent embodied, but then switches to 100 percent embodied. The wage premium rises by only 2.23 percent using the CPS May/ORG calibration and by only 2.85 percent using the State of Working America data. Again, the increases in the

[9]The increase in the 90-10 wage premium is 26.30 percent in the CPS May/ORG data and 20.34 percent in the State of Working America data.

Table 3: Demand-Driven Shifts in the Wage Premium

90-10 Wage Premium	CPS May/ORG 60% Emb	CPS May/ORG 0% Emb	State of Working America 60% Emb	State of Working America 0% Emb
Low Level (Data)	3.453	3.453	3.613	3.613
Expected High Level (100 % Embodied)	3.476	3.530	3.650	3.716
High Level (Data)	4.361	4.361	4.348	4.348

NOTE: Using the CPS May/ORG data, $S_0 = 12.651$ and $\phi = 1.650$ in 60% embodied and 40% disembodied technology case and $S_0 = 12.482$ and $\phi = 1.671$ in 0% embodied and 100% disembodied technology case. Using the State of Working America data, $S_0 = 12.127$ and $\phi = 1.717$ in the 60% embodied and 40% disembodied technology case and $S_0 = 11.938$ and $\phi = 1.741$ in the 0% embodied and 100% disembodied technology case.

wage premium indicated by the exercise are far below those observed in the data between the low level and high level periods.

From the perspective of this model, then, increases in the demand for skilled labor—arising from increases in the growth rate of embodied technology—do not appear to be a significant driver of the observed increase in the wage premium during the 1980s. The effect is simply too small.

4.2 Supply-Driven Shifts in the Wage Premium

This section examines whether labor supply factors may be able to account for the dramatic changes in wage inequality that took place in the United States in the 1980s. In particular, it asks: Can plausible shifts in the distribution of human capital account for the observed changes in inequality? Of course, the skill distribution is always shifting. However, it is unlikely that large shifts can take place in relatively short periods of time. Therefore, a supply-driven explanation of the wage premium associated with a changing skill distribution must be consistent with relatively small changes in this distribution over time.

In this exercise, the stationary distribution of human capital from the calibrated low level states for each of the CPS May/ORG and State of Working America data sets are altered sufficiently to match their respective high level states. This is done by altering the parameters of the human capital distribution, S_0 and ϕ, in order to match the high level wage premium while holding fixed the overall stock of human capital.[10] The results are reported in Tables 4 and 5.

Table 4: Values of S_0 and ϕ Required to Match the 90-10 Wage Premium

	CPS May/ORG		State of Working America	
	Low Level	High Level	Low Level	High Level
90-10 Wage Premium	3.453	4.361	3.613	4.348
S_0	12.651	10.199	12.127	10.228
ϕ	1.650	1.985	1.717	1.980

NOTE: The values of S_0 and ϕ are calculated for the 60% embodied and 40% disembodied technology case.

Increasing the wage premium by altering the distribution of human capital, while holding the stock of human capital fixed, requires an increase (in absolute value) in the slope parameter, ϕ, and a reduction in S_0. The results are reported in Table 4 for the calibration using the CPS May/ORG and the State of Working America data. To assess whether these changes, shown in Figure 2 for the CPS May.ORG case, are relatively small and hence feasible, the percent changes in human capital across the distribution by decile were computed. The results are reported in Table 5, where the highest skilled workers are in the 0-0.1 decile.

According to the model, the entire increase in the wage premium can be accounted for by a shift in human capital from the bottom six deciles of the distribution, 0.4-1.0, to the top four deciles, 0-0.4, with the largest gain occurring in the most highly

[10]Even though the total stock of human capital in the economy is changing over time, those changes should not affect the wage premium unless they change the shape of the distribution, i.e., its slope.

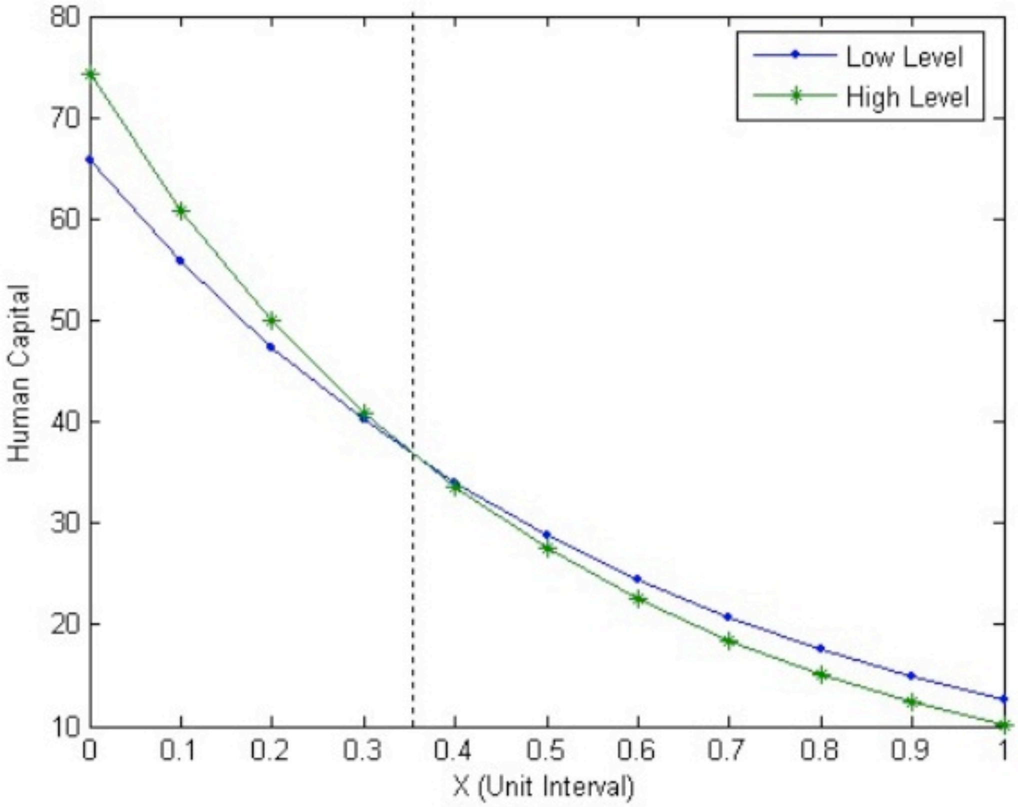


Figure 2: Changes Required in the Human Capital Distribution to Match the High Level 90-10 Wage Premium (based on the CPS May/ORG data).

skilled group of workers. Quantitatively, this means that the top 10 percent of the workforce by skill level would experience an increase of 2.04 percent in its share of the economy's total human capital based on CPS May/ORG data or 1.61 percent based on the State of Working America data. The largest decline would come from the bottom 10 percent of the workforce by skill level, with its share of the economy's total stock of human capital declining by just 0.77 percent based on the CPS May/ORG data or 0.60 percent based on the State of Working America data.

Table 5: Change Required in Human Capital Distribution by Decile

	CPS May/ORG		State of Working America	
Percentile	Change in Human Capital	% Change in Human Capital	Change in Human Capital	% Change in Human Capital
0-0.1	23.72	2.04	18.74	1.61
0.1-0.2	13.35	1.15	10.48	0.90
0.2-0.3	5.78	0.50	4.47	0.38
0.3-0.4	0.35	0.03	0.20	0.02
0.4-0.5	-3.43	-0.30	-2.76	-0.24
0.5-0.6	-5.97	-0.51	-4.73	-0.41
0.6-0.7	-7.57	-0.65	-5.95	-0.51
0.7-0.8	-8.47	-0.73	-6.63	-0.57
0.8-0.9	-8.87	-0.76	-6.91	-0.60
0.9-1.0	-8.90	-0.77	-6.91	-0.60

NOTE: The total stock of human capital in the economy is held fixed at the computed value of 1,161.21.

While the full explanation for the observed changes in wage inequality in the United States is not to be found in the shifting distribution of the economy's human capital, these estimates suggest that even modest changes in the skill distribution of the workforce could have very large effects on the wage premium.

5 Conclusions

This paper proposes an alternative approach to identifying the principal causes of the observed changes in income inequality in the United States. A vintage capital model is a natural framework for examining how new technology affects labor demand. This approach suggests that, absent frictions (such as retraining costs that may be required for workers to acquire the skills that are necessary to work with new technology), it is unlikely that an acceleration in the rate of technological advance alone can explain large movements in wage inequality. By contrast, factors that alter the skill distribution of the workforce appear to be a promising avenue of future research, since relatively small changes in the skill distribution can have large effects on the wage premia. Such factors could include immigration, population growth, or deficiencies in the educational system in failing to provide job-relevant training. At the high end of the skill distribution, endogenous increases in human capital may be taking place in locations such as Silicon valley. A particularly attractive avenue of future research would be to examine these issues within the context of a heterogeneous workforce where the distribution, and perhaps the level, of human capital is endogenously determined as the outcome of changing opportunities associated with the introduction of new technology and new goods into the economy.

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