Can't SBTC explain the U.S. wage inequality dynamics?

Yip, Chi Man

City University of Hong Kong

August 2010

1

Can't SBTC Explain the U.S. Wage Inequality Dynamics?

Chi Man YIP
City University of Hong Kong

May 27, 2011

Abstract

Based on the effect of skill-biased technology change (SBTC), this paper builds a search model with heterogeneous firms and workers to explain the dynamics of the wage inequality in the U.S. from 1963-2005. Firms differ in capital intensity (technology content) of the job created and workers differ in their education level. As the match-specific productivity is stochastic, the productivity threshold of employment of each education-job pair matched is endogenously determined. The advance in skill-biased technology increases the productivity of the highly educated workers as well as the capital intensity facing firms when creating high-tech jobs. We argue that in response to the rise in the capital intensity, high-tech firms increase the productivity thresholds of hiring, which leads to wage increment in the high-tech sector, and thus widening the residual wage inequality. Meanwhile, the increase in the productivity of the highly educated worker in the high-tech sector results in higher education premium in both the high-tech and low-tech sectors. Using the historical U.S. data, calibration shows that SBTC can explain the general trends in the education premium and the residual wage inequality from 1963-2005. In particular, it solves the puzzle why the education premium fell but the residual wage inequality grew in the early 1970s.

*This is a part of my M.Phil. thesis under the guidance of Dr. Lu Chia-Hui, to whom I am indebted. Remaining errors are mine.

1 Introduction

This paper develops a variant of the standard search model to investigate the key factors behind the dynamics of education premium and residual wage inequality in the U.S. during the period between 1963 and 2005. Using historical U.S. data to calibrate the model, we show that skill-biased technology change (SBTC) can explain general trends of wage inequality dynamics. In particular, our study reconciles five salient patterns of wage level and its inequality dynamics in the U.S. in the past four decades as documented by vast empirical studies. Specifically, the calibrated results show that: (i) the residual wage inequality exists not only in the highly educated group but also in the low-educated group, (ii) the residual wage inequality rises gradually, (iii) the education premium first falls in the 1970s, and then rises in the following period, (iv) the education premium has grown at a faster speed than the residual wage inequality since the mid-1980s, and (v) a real wage declines in the lower end of the wage distribution since 1960s. [1]

In addition, the model captures stylized facts that are well documented in the existing educational mismatch literature. In particular, the calibrated results show that: (i) both overeducation an undereducation are persistent[2], (ii) the overeducated are paid at a higher wage than their coworkers but are paid at a lower wage than those who possess similar education background and work in an occupation their education level is just demanded, and (iii) the undereducated are paid at a lower wage than their coworkers but are paid at a higher wage than those who possess similar education background and work in an occupation their education level is just demanded.[3]

We build a search model with heterogeneous workers and firms[4]. Workers differ in their education level and firms differ in the capital intensity of

[1]See Bound and Johnson (1992), Katz and Murphy (1992), Levy and Murnane (1992), Juhn et al. (1993), Card and DiNardo (2002), Lemieux (2006) and Autor et al. (2008).

[2]See Daly et al. (2000) for Germany, Rubb (2003) for the U.S. and Frenette (2004) for Canada.

[3]See Rumberger (1987), Verdugo and Verdugo (1989), Sicherman (1991), Kiker et al. (1997), Cohn and Ng (2000), Vahey (2000), Chevalier (2003) and McGuinness and Bennett (2007).

[4]This type of model matches several empirical regularities of creation and destruction of jobs over the real business cycle. See Merz (1995) and Cole and Rogerson (1999). However, Wong (2003) shows that Mortensen-Pissarides model fails to explain the U.S. wage inequality. Our analysis gives an insight into the literature to explain why these kinds of model also match several key feathers of wage inequality dynamics in the U.S.

the job created. In contrast to the standard search model with deterministic, match-independent productivity of workers, our model features match-specific, stochastic productivity draw. The productivity of workers of different education level is realized and becomes observable only after the worker and firm match in the labor market. We show that the endogenous productivity thresholds for successful employment are sufficient statistics to pin down the equilibrium expected wage of each education-job pair matched. As firms are competing for limited workers, and workers are competing for limited jobs, a change of one productivity threshold in response to a change of exogenous parameter will generate a spillover effect to the others as the values of outside options facing firms and workers will vary accordingly. It is shown in the paper that it is the general equilibrium effect which makes the impacts of SBTC propagate across different sectors and labor groups.

We argue that SBTC can explain the wage inequality dynamics should both the effect of biased productivity premium and the effect of capital intensity dispersion be considered. We show that the explaining power of the SBTC argument is crippled if either channel is omitted. A detailed discussion is provided below. This section discusses the evidence on the linkage between the U.S. wage inequality and SBTC. Section 2 presents the model setup, followed by the steady state equilibrium analysis in section 3. Calibration results are in section 4. Section 5 concludes the key findings of this paper.

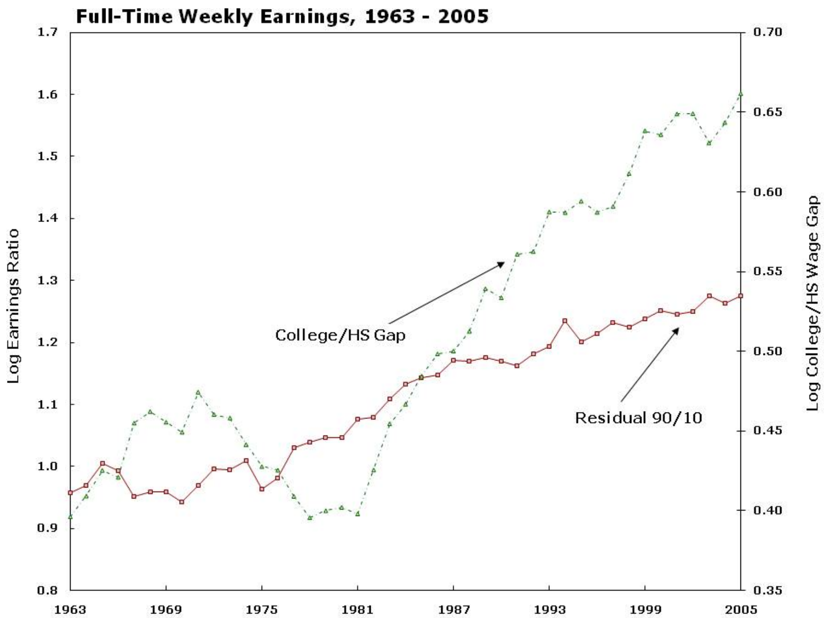
1.1 SBTC and The U.S. Wage Inequality

This subsection provides linkages between the wage inequality dynamics and two effects of SBTC, namely biased productivity premium (BPP) effect and capital intensity dispersion (CID) effect. Also, the key existing literature will be reviewed in this section.

Figure 1 illustrates the U.S. wage inequality dynamics during 1963-2005 using March Current Population Surveys[5]. As shown in figure 1, the college/high school wage gap and the residual 90/10 wage gap, controlling the measures of education, experience and gender, could be interpreted as education premium and residual wage inequality respectively. Several features of the wage inequality are demonstrated in figure 1: (i) residual wage inequality increased gradually, (ii) education premium declined in the early 1970s and

[5]Data are from Autor et al. (2008).

Figure 1: The U.S. Wage Inequality dynamics



rose in the other periods, and (iii) education premium grew more rapidly than residual wage inequality since the 1980s. In the 1990s, studies support the fact that SBTC is the driving force behind the wage inequality growth. A substantial amount of studies (Bound and Johnson, 1992; Katz and Murphy, 1992; Levy and Murnane, 1992; Juhn et al., 1993) document the rise in the wage inequality in the U.S. labor market in the 1970s and the 1980s. The growth was first attributed to the increase in the college-high school wage premium in the mid-1970s and the 1980s. (Bound and Johnson, 1992; Katz and Murphy, 1992). However, the observed characteristics such as education, working experience, age and gender can only explain a third of the wage inequality growth. Meanwhile, Juhn et al. (1993), DiNardo et al. (1996) and Gottschalk (1997) believe that the change in the residual wage inequality can explain most of the overall wage inequality growth. In particular, Juhn et al. (1993) argue that the increase in the relative demand for skill caused the residual wage inequality to rise in the 1970s and the 1980s. Krueger (1993), Berman et al. (1994), Autor et al. (1998), Bartel and Sicherman (1999) and Allen (2001) argue that the skill-biased technology change (SBTC) is the key factor behind such increase.

Nevertheless, challenges to the SBTC hypothesis have emerged since the late 1990s. For example, as pointed out by Lemieux (2006), if SBTC increases the demand for skill and thus widened the residual wage inequality in the past four decades, the growth of the education premium should be recognized as well. However, as documented in the existing literature (Juhn et al., 1993; Card and DiNardo, 2002; Lemieux, 2006; Autor et al., 2008), the U.S. education premium dropped in the early 1970s . This might not reconcile with the SBTC hypothesis.

The existing literature mainly interprets SBTC as the improvement in the productivity of the highly educated in the high-tech sector[6], namely biased productivity premium (BPP) effect. Since the skill-biased technology complements the skill the highly educated possess, SBTC keeps improving the productivity of the highly educated in the high-tech sector, generating the BPP effect and increasing education premium. Unsurprising, our model calibration, when considering BBP effect of SBTC only, captures an increasing trend of education premium, just as the calibration result of Wong (2003). This provides a linkage between SBTC and education premium.

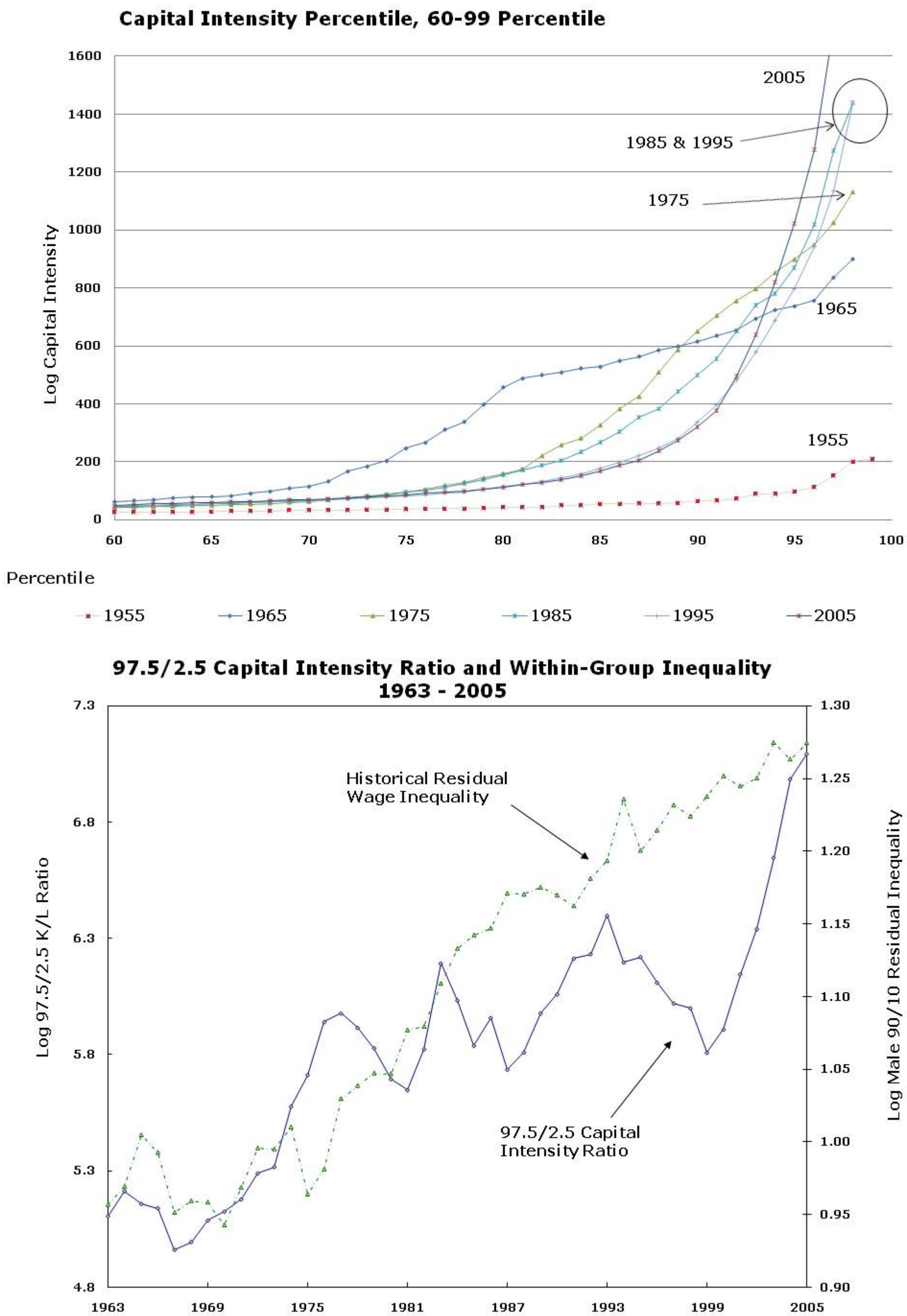
Another effect of SBTC, namely capital intensity dispersion (CID) effect, plays an important role in determining both residual wage inequality and education premium but is always neglected in the wage inequality literature. Caselli (1999) also documents that the difference in the capital-labor ratio between the 90th and the 10th percentile that has risen since the 1960s. As shown in figure 2A, the upper end of the distribution of the capital intensity (as measured by capital-labor ratio) rose sharply over time while it has not changed much in the rest of the distribution.

A few works in the existing literature examine the linkage between CID effect of SBTC and the wage inequality. This effect has largely increased the capital intensity dispersion between the high-tech and the low-tech sectors since the 1960s, inducing the residual wage inequality to rise (which will be shown later). A simple empirical study by Leonardi (2007) finds that the U.S. residual wage inequality can be explained by capital intensity. Apart from the existing literature, we plot the dynamics of the capital intensity dispersion and residual wage inequality during 1963-2005 in figure 2B.[7] We observe

[6] See Juhn et al. (1993), Krueger (1993), Berman et al. (1994), Autor et al. (1998), Bartel and Sicherman (1999), Allen (2001) and Autor et al. (2008).

[7] Residual wage inequality is from Autor et al. (2008). Capital intensity dispersion is measured by the ratio of the 97.5th percentile to 2.5th percentile capital-labor ratio. Data

Figure 2: Evidence on Capital Intensity Dispersion Effect of SBTC



that both the capital intensity dispersion and the residual wage inequality are moving on a similar trend. This evidence suggests that the CID effect of SBTC increases the relative demand for skills, thereby widening the residual wage inequality. Our calibration result shows that the CID effect of SBTC does increase residual wage inequality during 1963-2005.

Furthermore, our calibration results indicate that the simulated education premium and residual wage inequality are highly and positively correlated with the historical ones only if both the BPP effect and the CID effect are taken into account.

1.2 Related Theoretical Works

In theoretical search models of Albrecht and Vroman (2002), Shi (2002), Wong (2003) and Dolado et al. (2009), the skill-biased technology favors the highly educated; hence, their productivity is higher in the high-tech sector. These models predict that the BPP effect of SBTC improves the education premium. Analogously, Albrecht and Vroman (2002), Shi (2002) and Dolado et al. (2009) show that the BPP effect would also increase residual wage inequality. However, according to the critique of Lemieux (2006), the SBTC should not have reduced the education premium but at the same time increased residual wage inequality in the 1970s. Therefore, the BPP effect of the SBTC alone fails to explain the education premium dynamics in the U.S. in the early 1970s. Shi (2002) explains that the productivity slowdown is the driving force of the fall in the U.S. education premium in the 1970s. Analogously, Leonardi (2007) proves that the CID effect increases residual wage inequality. Since workers are homogenous in Leonardi (2007), no education premium issue can be examined.

Regarding the educational mismatch, not only the existing literature supports the persistence of overeducation and undereducation, but also the existence of overeducation and undereducation implies the existence of residual wage inequality in both educated groups in the search model. Albrecht and Vroman (2002), Leonardi (2007), Blazquez and Jansen (2008) and Dolado et al. (2009) do not allow undereducation, generating no residual wage inequality in the low-educated group.

Amongst the related theoretical works, only Shi (2002) and Wong (2003) allow both overeducation and undereducation. In Shi (2002), it is optimal

of capital and the number of employees are from COMPUSTAT.

for the highly educated workers to apply to high-tech jobs only. The absence of the overeducation implies the highly skilled only work in the high-tech sector and are thus paid the same, inducing no residual wage inequality in the highly educated group. In Wong (2003), both overeducation and undereducation coexist under a certain condition. In contrast, the introduction of the stochastic match-specific productivity and the productivity distribution of match with infinite upper bound ensures that both overeducation and undereducation coexist in our model. This allows us to simulate not only the dynamics of residual wage inequality in two educated groups, but also the dynamics of education premium in two sectors.

Acemoglu (1998, 1999, 2002, 2003) endogenizes the decision on technological progress, and shows that the increase in the relative supply of highly educated improves the marginal returns of R&D firms to advance the technology that complements the highly educated workers, inducing SBTC. Furthermore, Acemoglu (1998, 2002, 2003) shows that SBTC, in response to the sharp increase in the relative supply of the highly educated workers, increases the residual wage inequality as to why it followed an increasing trend since 1970s. In fact, SBTC should have also improved the education premium in the 1970s; however, Acemoglu (1998) argues that the relative supply of the highly educated increased so suddenly that SBTC progressed but did not respond fast enough. As a result, the effect of the increase in the relative supply of the highly educated first dominated the effect of SBTC as to why the education premium kept falling in the 1970s until SBTC fully responded to the relative supply of the highly educated in the 1980s. Under the assumption that the increase of the relative supply of highly educated workers is so sudden that SBTC did not response fast enough to such increase, Acemoglu (1998) succeeds in explaining why the education premium first declined and then rose again.

In Acemoglu (1998), the model assumes that regardless of the ability the highly educated workers and the low-educated workers can only work in the high-tech sector and low-tech sector respectively. Our model relaxes this assumption by allowing both overeducation and undereducation. In a steady state equilibrium, our model predicts that a fraction of the highly educated workers are willing to work in the low-tech sector because they are compensated with wages above their outside option values. Similarly, so long as the realized productivity is high enough, a high-tech vacancy is willing to hire the low-educated workers because lower wages are required compared to hiring the highly educated workers.

Furthermore, it is well known and is shown in figure 1 of Juhn et al.'s (1993) paper that the real wage in the lower end of the wage distribution kept falling in the 1970s and the 1980s. (i.e. $0 > \triangle w_{Lb}$)[8] In Acemoglu (1998), the residual wage inequality w_{Lg}/w_{Lb} rises because $\triangle w_{Lg} > \triangle w_{Lb} > 0$, which is inconsistent with the historical U.S. wage dynamics. On the contrary, our calibration result shows that $0 > \triangle w_{Lb}$ (which will be shown later), which captures the U.S. wage dynamics as well.

This paper develops a variant of search model to examine (i) the BPP effect, (ii) the CID effect, and (iii) the total SBTC effect on education premium and residual wage inequality. In contrast to the existing search models of heterogenous labors, the introduction of stochastic productivity realization ensures the existence of undereducation and overeducation in this model. This allows us to examine the impact of SBTC on not only the residual wage inequality in the upper and lower end of the distribution of the residual, but also the education premium in the low-tech and the high-tech sector. Calibration examines three cases: (i) the BPP effect, (ii) the CID effect, and (iii) the total SBTC effect. We find that the simulated residual wage inequality and education premium are highly and positively correlated with historical U.S. data only if both the BPP effect and CID effect are taken into account(as shown in calibration sector), suggesting that the SBTC hypothesis and the standard undirected search model are capable in explaining most of the wage inequality dynamics by means of a search model.

2 Model Setup

In this model, time is continuous. Workers and firms are risk neutral and have the same discounted rate r. Two types of worker exist in the economy, the highly educated H and the low-educated L. The population is constant and normalized to be one, i.e. $L_H + L_L = 1$. Two types of vacancy exist, the low-tech vacancy b and the high-tech vacancy g, each of which can only hire one worker. Firms are free to create vacancies. They first decide what type of vacancy to create. They need to purchase and install the job specific equipment k_j , where $k_b = k$ and $k_g = \sigma k$, $\sigma > 1$ before opening a vacancy[9].

[8] w_{Lb} and w_{Lg} are denoted as the wage of the low-educated workers in the low-tech sector and the high-tech sector respectively.

[9] Studies like Acemoglu (2001) assumes a fixed cost amount k_b and k_g are exogeneous while Leonardi (2007) endogenizes these fixed costs to analyze the capital-labor ratio

Workers and firms do not know the productivity, which is match-specific, before they contact each other during the job search process. Let δ_{ij} be the productivity level of worker i in vacancy j, where $i \in \{H, L\}$ and $j \in \{b, g\}$. The productivity of the matched worker follows a Pareto distribution $\delta_{ij} \sim Pareto(a, \underline{x}_{ij})$, in which the Pareto index $a > 1$ and the productivity distribution has a full support over $[\underline{x}_{ij}, \infty)$, where $\underline{x}_{ij} \geq 1$. The cumulative distribution function is:

$$F_{ij}(\delta) = \begin{cases} 1 - (\frac{\underline{x}_{ij}}{\delta})^a, & \text{for } \delta \geq \underline{x}_{ij}; \\ 0, & \text{for } \delta < \underline{x}_{ij}. \end{cases}$$

The assumption of Pareto productivity distribution captures two properties. First, the higher the productivity, the lower will be its likelihood, i.e. $f'(\delta) < 0$, where $f(\delta)$ is the density function. Second, no worker generates infinite amounts of goods, i.e. $\lim_{\delta \to \infty} f(\delta) = 0$.

We assume that the high-tech equipment complements the skill of the highly educated workers while the education level does not matter in the sector b. For simplicity, we assume that $\underline{x}_H > \underline{x}_L \geq 1$, where $\underline{x}_H \equiv \underline{x}_{Hg}$, and $\underline{x}_L \equiv \underline{x}_{Lg} = \underline{x}_{Hb} = \underline{x}_{Lb}$. The assumption implies: (i) regardless of the education level, a worker when matched with a vacancy b draws productivity from the same distribution and (ii) a worker H is more capable of operating high-tech equipment and thus able to produce more outputs than a worker L in the sector H.[10]

Workers and firms realize the productivity of the match when they come into contact. They agree to form the job match if both of them are satisfied with the bargaining wage. In case a worker i and a vacancy j form a job match, δ_{ij} units of output Y_j are generated until a shock arrives at an exogenous constant Poisson rate $\lambda > 0$. When this shock arrives, the worker becomes unemployed and the job is then unfilled. If either one rejects to form the job match for the instant, the job-seeker remains unemployed and the vacancy remains unfilled.

In contrast to standard search models of heterogenous agents[11], this model

decision of firms.

[10]The highly educated and the low-educated are just-qualified in the high-tech sector and the low-tech sector respectively. The highly educated are overeducated in the low-tech sector because their qualifications exceed the requirements of the occupation. Similarly, the low-educated are undereducated in the high-tech sector because they lack the qualifications required.

[11]See Acemoglu (2001), Albrecht and Vroman (2002), Shi (2002), Wong (2003), Dolado et al. (2009)

does not assume homogenous productivity level of the matches; instead, it introduces a stochastic productivity realization. This assumption captures the match-specific component, in which the productivity of a vacancy largely varies with workers of similar characteristics.[12] As a result, a portion of workers L possess higher productivity than worker H does, and vice versa.

2.1 Matching Technology

Let u_i and v_j be the unemployment of a worker i and a vacancy j respectively. Hence, $u = u_H + u_L$ and $v = v_b + v_g$ are respectively the unemployment and the amount of vacancies in the economy. The matching technology $M(u, v)$ is assumed to be differentiable and increasing in its arguments, concave, and constant returns to scale. The contact rate for a vacancy can be written as $M(u, v)/v$. Define $q(\theta) \equiv M(u, v)/v$ where $\theta \equiv v/u$ is the market tightness. It is straightforward to show that the labor contact rate is $M(u, v)/u = \theta q(\theta)$. Also, one can show that $q(\cdot)$ is a differentiable decreasing function. Furthermore, we assume $\lim_{\theta \to 0} q(\theta) = \infty$, $\lim_{\theta \to 0} \theta q(\theta) = 0$, $\lim_{\theta \to \infty} q(\theta) = 0$ and $\lim_{\theta \to \infty} \theta q(\theta) = \infty$.

After a worker i and a vacancy j meet via the matching technology function, both parties realize the productivity δ_{ij} of the match. When both parties agree with the bargaining wage, they sign into a contract. Otherwise the job-seeker remains unemployed and the vacancy remains unfilled in the next instant.[13]

2.2 Labor Market

The equilibrium will be characterized through a series of Bellman equations. Let J_{ij}^E and J_i^U be the discounted present value of being employed of a worker i in a vacancy j and the discounted present value of a worker i being unemployed respectively. Let $w_{ij}(\delta_{ij})$ be the wage of the worker i in the vacancy j. $J_{ij}^E(\delta_{ij})$ is written as:

$$rJ_{ij}^E(\delta_{ij}) = w_{ij}(\delta_{ij}) + \lambda(J_i^U - J_{ij}^E(\delta_{ij})) \tag{1}$$

[12] Jovanovic (1979) also introduces the stochastic job matchings to analyze worker turnover.

[13] Empirical evidence strongly supports this job-contact effect. Interested readers are referred to Barron (1975) and Pissarides (1986).

A worker i receives a wage w_{ij} in a vacancy j and separates from it at a rate λ to become unemployed. Let $\phi_v \equiv v_b/v$ be the fraction of the low-tech vacancies amongst all vacancies. Similarly, we can write J_i^U as:

$$\begin{aligned} rJ_i^U &= z + \theta q(\theta)\{\phi_v \int [\max\{J_{ib}^E(\delta_{ib}), J_i^U\} - J_i^U] dF_{ib}(\delta_{ib}) \\ &\quad +(1-\phi_v)\int [\max\{J_{ig}^E(\delta_{ig}), J_i^U\} - J_i^U] dF_{ig}(\delta_{ig})\} \end{aligned} \tag{2}$$

where z is the non-market income[14]. Also, let $J_{ij}^F(\delta_{ij})$ be the discounted present value of a filled vacancy j that is occupied by a worker i and J_j^V be the discounted present value of an unfilled vacancy j. $J_{ij}^F(\delta_{ij})$ can be written as:

$$rJ_{ij}^F(\delta_{ij}) = P_j\delta_{ij} - w_{ij}(\delta_{ij}) + \lambda(J_j^V - J_{ij}^F(\delta_{ij})) \tag{3}$$

where P_j is a price of good j. A filled vacancy j receives revenue $P_j\delta_{ij}$ and rewards the worker i a wage $w_{ij}(\delta_{ij})$. Again, a filled vacancy j also separates from the match at a rate λ to become unfilled. We may assume that P_j depends on the relative supply of the good j. To simplify the analysis, P_b (P_g) is assumed to be decreasing (increasing) in ϕ_v. Let $\phi_u \equiv u_L/u$ be the unemployment of the worker L. As for the discounted present value of being a vacancy j, it can be written as follows:

$$\begin{aligned} rJ_j^V &= q(\theta)[\phi_u(\int \max\{J_{Lj}^F(\delta_{Lj}), J_j^V\} - J_j^V dF_{ij}(\delta_{Lj})) \\ &\quad +(1-\phi_u)(\int \max\{J_{Hj}^F(\delta_{Hj}), J_j^V\} - J_j^V dF_{ij}(\delta_{Hj}))] \end{aligned} \tag{4}$$

Free entry ensures that vacancies are created until all rents are exhausted in the equilibrium; hence, the following hold in the steady state equilibrium:

$$J_j^V = k_j \tag{5}$$

Following the literature (Acemoglu, 2001; Albrecht and Vroman, 2002; Wong, 2003; Leonardi, 2007), wage is the one that maximizes the Nash product $(J_{ij}^E(\delta_{ij}) - J_i^U(\delta_{ij}))^\beta (J_{ij}^F(\delta_{ij}) - J_j^V(\delta_{ij}))^{1-\beta}$ to split the matching surplus, where $\beta \in (0,1)$ is the bargaining power of workers. It can be found that a wage $w_{ij}(\delta_{ij})$ is the solution of the following equations:

$$J_{ij}^E(\delta_{ij}) - J_i^U = \beta(J_{ij}^E(\delta_{ij}) - J_i^U + J_{ij}^F(\delta_{ij}) - J_j^V) \tag{6}$$

[14]The unemployment insurance can be financed by a lump sum tax payment.

Intuitively, a worker i shares a fraction of the total matching surplus. Using the equations (1), (3) and (6), the wage equations are as follows:

$$w_{ij}(\delta_{ij}) = rJ_i^U + \beta(P_j\delta_{ij} - rJ_i^U - rk_j) \tag{7}$$

Intuitively, a worker i is compensated with their outside option values and a fraction of the matching surplus. Using equations (1), (3) and (7), one can easily verify that $\partial J_{ij}^E(\delta_{ij})/\partial\delta_{ij} > 0$ and $\partial J_{ij}^F(\delta_{ij})/\partial\delta_{ij} > 0$. Hence, using equations (6) there exists a unique reservation productivity level δ_{ij}^R such that

$$J_{ij}^E(\delta_{ij}^R) = J_i^U, J_{ij}^F(\delta_{ij}^R) = J_j^V \tag{8}$$

Intuitively, a worker i accepts the job offer if the discounted present value of working in a vacancy j is at least as high as the outside option value J_i^U. A vacancy j contract with a worker i only if the discounted present value of being filled $J_{ij}^F(\delta_{ij}^R)$ is at least as high as their outside option value J_j^V. The uniqueness of δ_{ij}^R implies that a worker i and a vacancy j are willing to get into a contract for all realized productivity levels exceeding δ_{ij}^R. When contacted, a worker i and a vacancy j form a job match at the rate of $1 - F(\delta_{ij}^R)$. Write $\Upsilon_i(\phi_v)$ as $\phi_v(1 - F_{ib}(\delta_{ib}^R)) + (1 - \phi_v)(1 - F_{ig}(\delta_{ig}^R))$, e_{ij} as the number of employed workers i in the vacancy j, and $\phi_e \equiv (e_{Lb} + e_{Lg})/e$ as the fraction of the low-educated employment among all the employment e. In a steady state, following equations hold:

$$\lambda(1 - u)(1 - \phi_e) = \theta q(\theta)\Upsilon_H(\phi_v)u(1 - \phi_u) \tag{9}$$

$$\lambda(1 - u)\phi_e = \theta q(\theta)\Upsilon_L(\phi_v)u\phi_u \tag{10}$$

$$L_H = (1 - u)(1 - \phi_e) + u(1 - \phi_u) \tag{11}$$

Equations (9) and (10) imply that u_H and u_L are constant respectively; hence, equation (11) implies that ϕ_e is constant. If ϕ_e, ϕ_u, ϕ_v and δ_{ij}^R, $\forall i, j$ remain unchanged, the equations (9) and (10) also ensure that all e_{ij} are constant in the steady state equilibrium.

3 Steady State Equilibrium

A steady state equilibrium is defined as value functions J_{ij}^E, J_{ij}^F, J_i^U and J_j^V, wages w_{ij}, reservation productivity level δ_{ij}^R, the proportion of low-educated employment ϕ_e and low-educated unemployment ϕ_u, the fraction of low-tech vacancy ϕ_v, unemployment u and market tightness θ such that the equations (1)- (6), (8)-(11) are satisfied for all $i \in \{H, L\}$ and $j \in \{b, g\}$. Using the equations (9) and (10), the steady state unemployment of the worker i are given by:

$$u_H = \frac{\lambda e_H}{\theta q(\theta)\Upsilon_H(\phi_v)},\ u_L = \frac{\lambda e_L}{\theta q(\theta)\Upsilon_L(\phi_v)} \tag{12}$$

From equation (12), the steady state fraction of low-educated employment is as follows:

$$\phi_e = \frac{\Upsilon_L(\phi_v)\phi_u}{\Upsilon_L(\phi_v)\phi_u + \Upsilon_H(\phi_v)(1-\phi_u)} \in (0,1) \tag{13}$$

Using equations (12) and (13) and the accounting identity $e = 1 - u$, steady state unemployment is obtained as follows:

$$u = \frac{\lambda}{\lambda + \theta q(\theta)[\Upsilon_L(\phi_v)\phi_u + \Upsilon_H(\phi_v)(1-\phi_u)]} \in (0,1) \tag{14}$$

Using equations (11), (13) and (14), the fraction of low-educated unemployed among the unemployed can be obtained as:

$$\phi_u = \frac{(1-L_H)[\lambda + \theta q(\theta)\Upsilon_H(\phi_v)]}{\lambda + \theta q(\theta)(\Upsilon_H(\phi_v)(1-L_H) + \Upsilon_L(\phi_v)L_H)} \in (0,1) \tag{15}$$

The steady state production of the goods $Y_j = e_{Hj}\mathbf{E}(\delta_{Hj}|\delta_{Hj} \geq \delta^R_{Hj}) + e_{Lj}\mathbf{E}(\delta_{Lj}|\delta_{Lj} \geq \delta^R_{Lj})$, where $\mathbf{E}(\cdot)$ is an expectation operator. The match generates output only if the realized productivity exceeds the reservation level. Hence, on average, the observed output level of a worker i is $\mathbf{E}(\delta_{ij}|\delta_{ij} \geq \delta^R_{ij})$ in a vacancy j. Using the equations (1), (2) and $J^E_{ij}(\delta^R_{ij}) = J^U_i$, it is interesting to note that the reservation wages w^R_{ij} equal the outside option value rJ^U_i in the steady state equilibrium. Similarly, using the equations (1), (2), (3) and (5), we have:

$$P_j\delta^R_{ij} = rJ^U_i + rk_j \tag{16}$$

Intuitively, a contract is signed only if the realized revenue $P_j\delta_{ij}$ is high enough to cover an outside option value of a worker rJ^U_i and rental rk_j. Using the equations (1), (2) and (7), the outside option values can be rewritten as follows:

$$\begin{aligned} rJ^U_i = z + \theta q(\theta)[\phi_v(&\int_{\delta^R_{ib}}^{\infty}(P_b\delta_{ib} - rJ^U_i - rk)dF_{ib}(\delta_{ib})) \\ &+(1-\phi_v)(\int_{\delta^R_{ig}}^{\infty}(P_g\delta_{ig} - rJ^U_i - \sigma rk)dF_{ig}(\delta_{ig}))] \end{aligned} \tag{17}$$

It is straightforward to show that the outside option values straightly decrease with ϕ_v and increasing with θ. Intuitively, the rise in ϕ_v increases the fraction of the low-tech vacancy that generates lower returns, reducing the expected returns of the unemployed. Also, the rise in θ increases the tightness of the labor market, improving the chance of the workers to find a vacancy and thus the outside option value. Using the equations (3), (4), (5) and (7), we obtain two equilibrium conditions:

$$\begin{aligned}\frac{(r+\lambda)}{(1-\beta)}rk &= q(\theta)[\phi_u(\int_{\delta_{Lb}^R}^{\infty}(P_b\delta_{Lb}-P_b\delta_{Lb}^R)dF_{Lb}(\delta_{Lb})) \\ &+(1-\phi_u)(\int_{\delta_{Hb}^R}^{\infty}(P_b\delta_{Hb}-P_b\delta_{Hb}^R)dF_{Hb}(\delta_{Hb}))] \qquad (18)\end{aligned}$$

$$\begin{aligned}\frac{(r+\lambda)}{(1-\beta)}\sigma rk &= q(\theta)[\phi_u(\int_{\delta_{Lg}^R}^{\infty}(P_g\delta_{Lg}-P_g\delta_{Lg}^R)dF_{Lg}(\delta_{Lg})) \\ &+(1-\phi_u)(\int_{\delta_{Hg}^R}^{\infty}(P_g\delta_{Hg}-P_g\delta_{Hg}^R)dF_{Hg}(\delta_{Hg}))] \qquad (19)\end{aligned}$$

Lemma 1. *In a steady state equilibrium, a worker H possesses a higher outside option value than a worker L. $J_H^U > J_L^U$ and the high-tech goods are more experience than the low-tech ones. $P_g > P_b$.*

Proof. See the appendix. □

A worker H, on average, generates a higher productivity level than a worker L in the sector g. Rent-sharing ensures the worker H is rewarded with higher average wage. Therefore, the highly educated possesses a higher outside option value than the low-educated.

Proposition 1. *Having an identical output level, the following inequalities hold in the steady state:*

1. *For all $\delta > \max\{\delta_{Hj}^R, \delta_{Lj}^R\}$, $w_{Hj}(\delta) > w_{Lj}(\delta)$.*

2. *For all $\delta > \max\{\delta_{ib}^R, \delta_{ig}^R\}$, $w_{ib}(\delta) < w_{ig}(\delta)$ iff $\delta > \frac{(\sigma-1)rk}{\beta(P_g-P_b)}$.*

Proof. See the appendix. □

The first and the second implication of the proposition (1) compare wages across education groups and within groups respectively. The first one implies that with identical output level a worker H receives a higher wage than a worker L. Intuitively, the highly educated possesses a higher outside option value than the low-educated and hence are compensated with a higher wage. The second implication predicts that generating the same amount of output level, a worker i receives a higher wage in the sector g only if the output level δ_{ij} is sufficiently high such that the revenue share differentials $\beta(P_g\delta_{ig} - P_b\delta_{ib})$ exceed the rental cost differentials $(\sigma - 1)rk$.

In the existing literature (Albrecht and Vroman, 2002; Shi, 2002; Blazquez and Jansen, 2008), it is a general implication that the highly educated receive a higher wage in the high-tech sector than in the low-tech sector because revenue differentials are assumed to be higher than rental differentials. Hence, this model gives an intuition on the condition under which a worker i indeed receive a lower wage in the high-tech sector than in the low-tech even though they might do similar work and generate a similar output level.

A worker i generates δ_{ij} unit of output in sector j and receives a wage $w_{ij}(\delta_{ij})$ only if $\delta_{ij} \geq \delta_{ij}^R$ when matched. On average, the observed wage of a worker i is $\mathbf{E}(w_{ij}(\delta_{ij})|\delta_{ij} \geq \delta_{ij}^R)$ in the sector j. Wage inequality is taken to be a log ratio of the average observed wages of two groups of workers. Education premium can be written as follows:

$$\begin{aligned} \ln \frac{\mathbf{E}(w_{Hj}(\delta)|\delta \geq \delta_{Hj}^R)}{\mathbf{E}(w_{Lj}(\delta)|\delta \geq \delta_{Lj}^R)} &= \ln \frac{\frac{\beta P_j \int_{\delta_{Hj}^R}^{\infty} \delta_{Hj} - \delta_{Hj}^R dF_{Hj}(\delta_{Hj})}{1 - F_{Hj}(\delta_{Hj}^R)} + rJ_H^U}{\frac{\beta P_j \int_{\delta_{Lj}^R}^{\infty} \delta_{Lj} - \delta_{Lj}^R dF_{Lj}(\delta_{Lj})}{1 - F_{Lj}(\delta_{Lj}^R)} + rJ_L^U} \\ &= \ln \frac{[a - (1-\beta)]rJ_H^U + \beta r k_j}{[a - (1-\beta)]rJ_L^U + \beta r k_j} > 0 \qquad (20) \end{aligned}$$

Similarly, residual wage inequality is as follows:

$$\ln \frac{\mathbf{E}(w_{ig}(\delta)|\delta \geq \delta_{ig}^R)}{\mathbf{E}(w_{ib}(\delta)|\delta \geq \delta_{ib}^R)} = \ln \frac{[a - (1-\beta)]rJ_i^U + \beta\sigma r k}{[a - (1-\beta)]rJ_i^U + \beta r k} > 0 \qquad (21)$$

Education premium arises from differentials in the outside option values of two education groups while the capital intensity dispersion ($\sigma > 1$) creates residual wage inequality in two different education groups. Proposition (2) summarizes the results.

Proposition 2. *The steady state equilibrium wage structure of the economy are as follows:*

1. $\mathbf{E}(w_{Hj}(\delta_{Hj})|\delta_{Hj} \geq \delta^R_{Hj}) > \mathbf{E}(w_{Lj}(\delta_{Lj})|\delta_{Lj} \geq \delta^R_{Lj})$
2. $\mathbf{E}(w_{ib}(\delta_{ib})|\delta_{ib} \geq \delta^R_{ib}) < \mathbf{E}(w_{ig}(\delta_{ig})|\delta_{ig} \geq \delta^R_{ig})$

The first implication compares a mean wage across education groups. It predicts that a worker H receives a higher mean wage than a worker L within the same sector. This implication also reconciles with educational mismatch literature[15], which supports the fact that, on average, the overeducated (undereducated) are paid at a higher (lower) wage than their co-workers. In this model, a worker H is overeducated in the sector b; hence, the overeducated receives a higher mean wage than his/her co-worker in the low-tech sector. Similar, a worker L are undereducated in the sector g; therefore, the undereducated are paid at a lower mean wage than his/her co-worker in the high-tech sector.

The second implication of the proposition (2) compares a mean wage within education group. It predicts that on average a worker i receives higher wages in the sector g than in the sector b, which is consistent with two empirical findings. First, it predicts that for a worker i with identical education background, vacancies, that pay higher wages on average, are more capital intensive, which is in accord with the empirical findings from Abowd et al. (1999). Second, it predicts that the overeducated (undereducated) on average receive a lower (higher) wage than those who possess similar education background and are just-qualified. This implication completes the story of the wage structure that is well documented in the educational mismatch literature.[16]

4 Model Simulation

In this section, calibration of the BPP effect, the CID effect and the total effect of SBTC are conducted separately using the historical U.S. data during 1963-2005. The first two calibration exercises aim to show that the wage

[15]See Rumberger (1987), Verdugo and Verdugo (1989), Sicherman (1991), Kiker et al. (1997), Cohn and Ng (2000), Vahey (2000), Chevalier (2003) and McGuinness and Bennett (2007).

[16]See footnote 15.

inequality dynamics cannot be captured if either BPP effect or CID effect is omitted as to why Wong (2003) concludes that Mortensen-Pissarides model cannot explain the wage inequality dynamics. The last calibration result will give a clear picture that the total effect of SBTC is capable in explaining both the education premium and the residual wage inequality by capturing major features of the wage inequality dynamics.

Exogenous parameters include a, λ, r, m, z, L, β, ξ, $\underline{x}_L$, $\underline{x}_H$, σ and k. The measures of the capital-labor ratio k, the capital intensity dispersion σ and the biased productivity premium are mainly from COMPUSTAT. In the model, k is the capital-labor ratio of low-tech vacancies. Capital, acquired from COMPUSTAT, is deflated using the deflator in real 2005 dollar from the Bureau of Economic Analysis. The deflated capital is then divided by the number of employees from COMPUSTAT to obtain the real capital intensity. $k_{p,t}$ denotes the p percentile of the capital-labor ratio in year t.[17] We assume that SBTC has no impact on the capital-labor ratio in the low-tech sector.[18] k is the average of the 2.5th percentile capital-labor ratio $k_{2.5,t}$ over the period 1963-2005 as follows:

$$k = \frac{1}{2005 - 1963} \sum_{t=1963}^{2005} k_{2.5,t}$$

Capital intensity is measured by the capital-labor ratio. Hence, $k = 3.58$ is used as the capital intensity in the low-tech sector. σ_t measures the capital intensity dispersion between a high-tech vacancy and the low-tech vacancy. This paper takes the ratio of the 97.5th percentile capital intensity to the 2.5th percentile capital intensity as the measure of the capital intensity dispersion each year, i.e. $\sigma_t = k_{97.5,t}/k_{2.5,t}$.

A mean productivity is computed using an AK model, i.e $a\underline{x}_{j,t}/(a-1) = Ak_{j,t}$, where $a\underline{x}_{j,t}/(a-1)$ is the mean of a Pareto productivity distribution, A is a fixed production parameter and $k_{j,t}$ is the average capital-labor ratio in the sector j. Hence, it is easy to deduce that the lowest realized productivity level equals $\underline{x}_{j,t} = Ak_{j,t}(a-1)/a$. To capture the biased productivity dispersion effect in $\underline{x}_{H,t}$, the lowest realized productivity level $\underline{x}_L$ is normalized to one. Then, $\underline{x}_{H,t} = (a(a-1)Ak_{g,t}/a(a-1)Ak_{b,t}) \times \underline{x}_L = k_{g,t}/k_{b,t}$. $k_{b,t}$ and $k_{g,t}$

[17] The 1st percentile of the capital-labor ratio is discarded because a few capital-labor ratios are close to zero in the lower end of the distribution of the capital-labor percentile.

[18] From figure 2A, one can notice that the lower end of the distribution of the capital-labor percentile has not changed much in the past 4 decades.

are the average of the capital intensity of the bottom 5th percentile and the top 5th percentile of the distribution respectively as follows:

$$k_{b,t} = \frac{1}{5}\sum_{p=2}^{6} k_{p,t}, \ \ k_{g,t} = \frac{1}{5}\sum_{p=95}^{99} k_{p,t}$$

Due to the lack of evidence on the Pareto index a, and the Pareto index is set at $a = 2$. The rest of the parameters follow the existing literature. To match the sample average for job destruction rate (Davis and Haltiwanger, 1992), we set the destruction rate at $\lambda = 0.055$. Following Wong (2003), we assume that the matching function forms as Cobb-Douglas function $q(\theta) = m \times \theta^{-\xi}$, where $\xi \in (0, 1)$, and the discount rate is set at $r = 0.04$ to reflect an annual rate of 4%, the scale parameter of the job-contact function $m = 0.768$, the unemployment benefit at $z = 0.475$, the fraction of the highly educated as $L = 0.281$ and workers' surplus share at $\beta = 0.5$. Similarly, we follow Albrecht and Vroman (2002) to set the elasticity of the matching function at $\xi = 0.5$. We need to explicitly specify the function of P_j. Since P_b is inversely related to ϕ_v, we, to simplify the analysis, take $P_b = \alpha(\frac{1}{\phi_v})^{1-\gamma}$ and $P_g = (1-\alpha)(\frac{1}{1-\phi_v})^{1-\gamma}$, similar to Acemoglu (2001). To reflect the equal importance of both goods Y_b and Y_g, we set $\alpha = 0.5$ and $\gamma = 0.5$.

Two effects (the BPP effect and CID effect) and the total effect of SBTC are examined in the following section. Calibration results support the fact that SBTC alone is sufficient to explain the dynamics of the education premium and the residual wage inequality in the past four decades. In addition, we show that the explaining power of the SBTC argument on education premium (residual wage inequality) is crippled if the biased productivity premium effect (residual wage inequality effect) is omitted.

4.1 Biased Productivity Premium Effect

Figure 3 illustrates the simulated education premium and residual wage inequality under the biased productivity premium effect. The capital intensity dispersion σ is constant in this study and is measured by its average as follows:

$$\sigma = \frac{1}{2005-1963}\sum_{t=1963}^{2005} \sigma_t$$

Not surprisingly, figure 3B illustrates that education premium follows an increasing trend under this effect, which is in line with Juhn et al. (1993), Wong (2003) and Autor et al. (2008). Intuitively, the BPP effect improves the productivity of the highly educated in the high-tech sector, thereby increasing the flow profit of the match and thus rewarding them with a higher wage. Hence, the BPP effect improves the education premium in the high-tech sector.

In addition, such increase in the average wage of the highly educated improves rJ_H^U. Although the BPP effect takes place in the high-tech sector, the increase in rJ_H^U rewards them a higher average wage in the low-tech sector. As a result, the BPP effect ameliorates the education premium in both sectors. From table 1, the correlations between historical U.S. education premium and the simulated ones in two sectors are over 0.9, reflecting the high explaining power of the BPP effect on education premium.

Proposition 3. *Biased productivity premium effect of SBTC improves education premium in both sectors.*

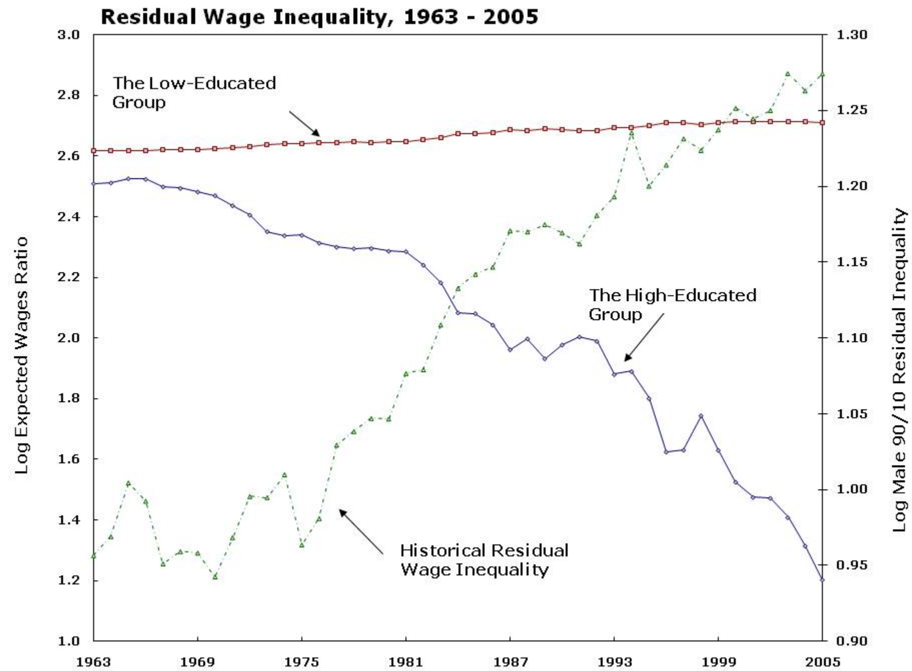
The BPP effect of SBTC alone fails to explain residual wage inequality dynamics in the U.S. According to table 1, the correlation between the simulated residual wage inequality in the highly educated group and the historical one is -0.9486. Figure 3a also demonstrates the falling trend of the residual wage inequality in the highly educated group.

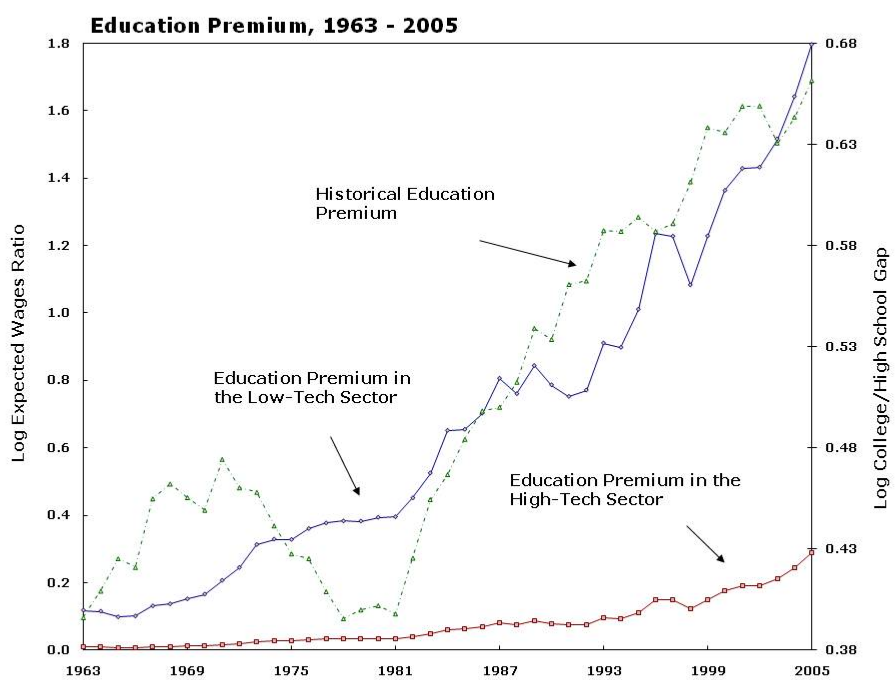
In Wong (2003), the model simulation predicts that the BPP effect reduces the residual wage inequality, which is measured by the average of the residual wage inequality in two education groups. In our model, the BPP effect largely reduces the residual wage inequality in the highly educated group and does not change much of the residual wage inequality in the low-educated group. Taking the average of the residual wage inequality in two different education groups, the BPP effect also reduces the simulated residual wage inequality in our model. Without considering the CID effect, our calibration result is consistent with the result from Wong (2003), in which she concludes that the Mortensen-Pissarides model is incapable of explaining the wage inequality in the U.S.

4.2 Capital Intensity Dispersion Effect

This section calibrates the model to examine the CID effect on residual wage inequality and education premium. In this section, the biased productivity

Figure 3: Simulated Results: Biased Productivity Premium Effect of SBTC





premium $\underline{x}_H$ is constant and is measured by its average as follows:

$$\underline{x}_H = \frac{1}{2005 - 1963} \sum_{t=1963}^{2005} \underline{x}_{H,t}$$

As shown in figure 2, the capital intensity dispersion and the historical residual wage inequality are moving on a similar trend. Hence, one could expect that the simulated residual wage inequality in two education groups are increasing as demonstrated in figure 4A. Table 1 shows that the correlations between the historical residual wage inequality and the simulated ones are over 0.8. These high and positive correlations reflect the high explaining power of the CID effect on residual wage inequality. Intuitively, the rise in the capital instalment cost increases the reservation thresholds δ_{ig}^{R} when a worker i matches a vacancy g so as to cover higher installment cost k_g. As a result, the mean wage of a worker i increase in the high-tech sector, widening the wage inequality of the worker i between two sectors. In other words, the residual wage inequality rises in both the highly educated group and the low-educated group.

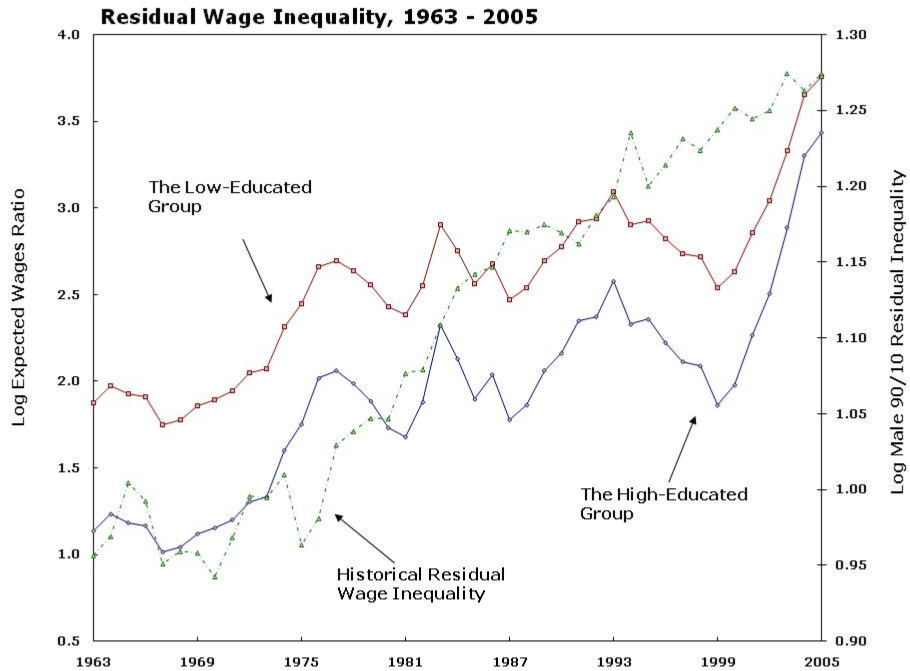
Proposition 4. *Capital intensity dispersion effect of SBTC increases residual wage inequality in both educated groups and reduces education premium in all sectors.*

When considering CID effect, the simulated education premium kept falling as shown in figure 4. In addition, table 1 shows the negative correlation between the historical education premium and the simulated ones, suggesting the incapability of the CIP effect in explaining the education premium.

4.3 Total SBTC Effect

Considering both the BPP effect and the CID effect, the simulated results, as shown in figure 5A and 5B, illustrate that education premium was on an increasing trend in both sectors during the period 1963-2005. In particular, education premium falls in the mid-1970s because the CID effect dominates the BPP effect during this period. In addition, figure 5 shows the variation of the residual wage inequality in both the highly educated group and the low-educated group, in which the simulated residual wage inequality increase during 1963-2005.

Figure 4: Simulated Results: Capital Intensity Dispersion Effect of SBTC



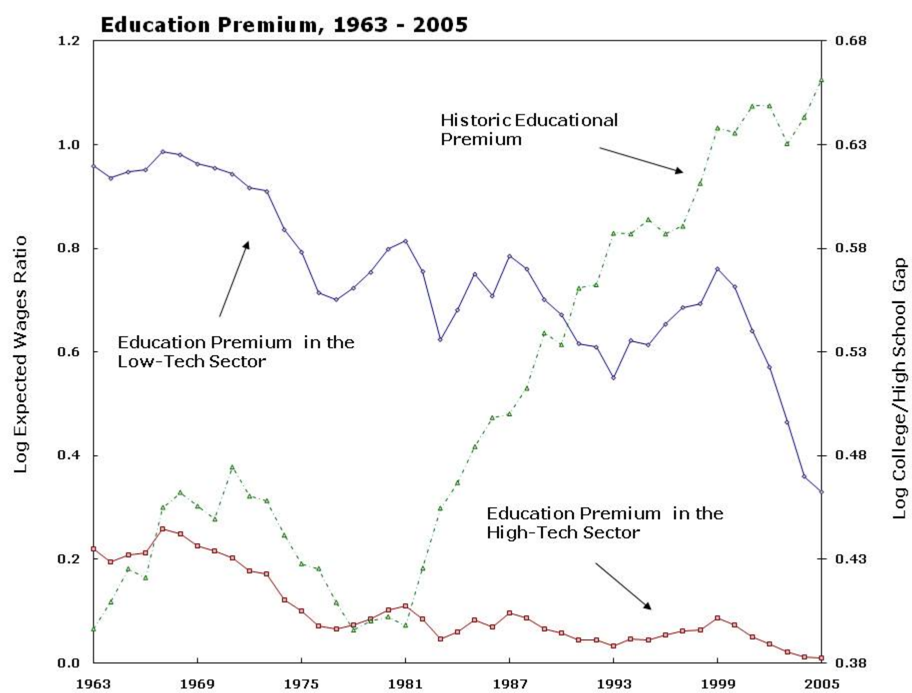


Figure 5D indexes the wage inequalities based on their values in the 1970s. Both the indexed education premium and residual wage inequality do not change much before the 1980s. The calibration result shows that the indexed education premium has grown faster than the indexed residual wage inequality after the mid-1980s. Table 1 also shows the positive correlations between the simulated and the historical data. We can therefore conclude that the total SBTC effect can explain the dynamics of both the U.S. education premium and residual wage inequality during 1963-2005.

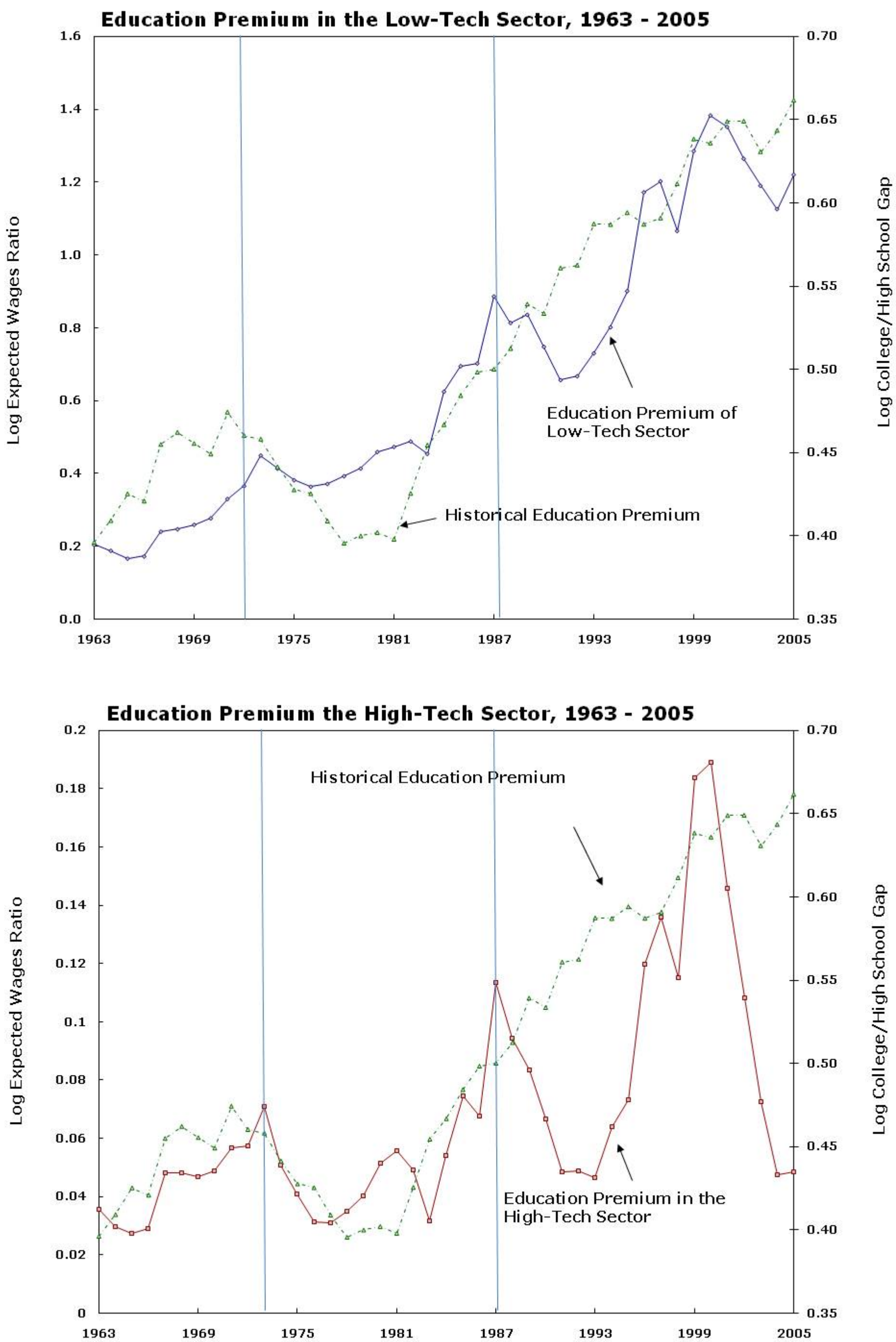
As documented in the existing literature, wages kept falling in the lower end of the wage distribution since 1970s. In Acemoglu (1998), the wages increase in all the wage groups. His model succeeds in predicting the increase in the residual wage inequality; however, such increase arises because of $\triangle w_{Lg} > \triangle w_{Lb} > 0$. In contrast to Acemoglu (1998), our implication of the increase in the residual wage inequality amongst the low-educated is $\triangle w_{Lg} > 0 > \triangle w_{Lb}$. As illustrated in the figure 5e, in the low-tech sector the average wage of the low-educated kept declining after mid 1960s. Proposition (5) summarizes the result.

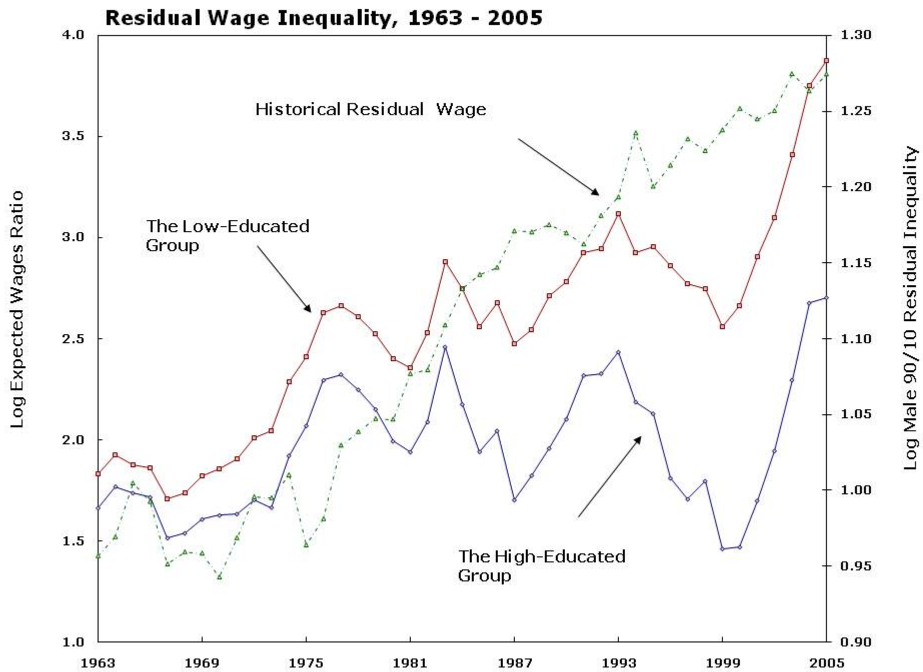
Proposition 5. *Total effect of SBTC are as follows:*

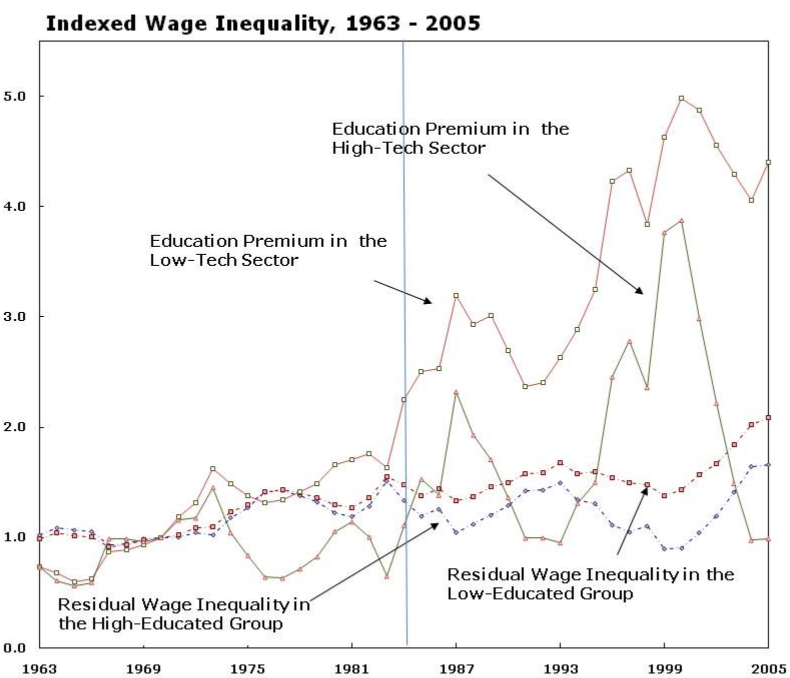
1. *Residual wage inequality widens gradually during 1963-2005;*
2. *Education premium falls in the mid-1970s, and rises in other periods;*
3. *Growth in education premium surpasses that in residual wage inequality after 1980s;*
4. *An average wage of the low-educated fell in the low-tech sector after mid-1960s.*

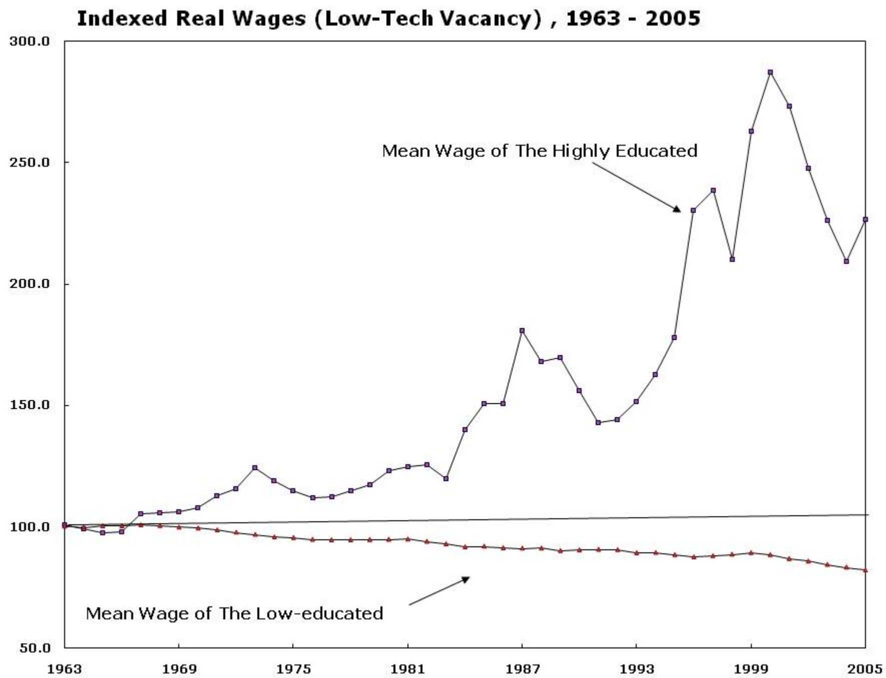
As shown in the figure 5 A-D, both overeducation and undereducation exists in the steady state equilibrium. Their existence is important to the wage inequality literature in that overeducation and undereducation generate the residual wage inequality in the highly educated group and the low-educated group respectively. The wage inequality literature supports the fact that residual wage inequality exists in both the upper and lower end of the distribution of the residuals (Katz and Murphy, 1992; Lemieux, 2006; Autor et al., 2008). Moreover, Lemieux (2006) and Autor et al. (2008) find that residual wage inequality grows substantially among college-educated workers. Hence, analyzing the residual wage inequality dynamics necessitates a model

Figure 5: Simulated Results: Total SBTC Effect




Residual Wage Inequality, 1963 - 2005
Historical Residual Wage
The Low-Educated Group
The High-Educated Group
Log Expected Wages Ratio
Log Male 90/10 Residual Inequality
1963
1969
1975
1981
1987
1993
1999
2005


Indexed Wage Inequality, 1963 - 2005
Education Premium in the High-Tech Sector
Education Premium in the Low-Tech Sector
Residual Wage Inequality in the Low-Educated Group
Residual Wage Inequality in the High-Educated Group
1963
1969
1975
1981
1987
1993
1999
2005



in which both overeducation and undereducation coexist in the equilibrium. The existing models neglect either overeducation or undereducation.[19] In contrast to these models, the introduction of stochastic productivity realization and the productivity distribution with infinite upper bound ensures the incidence of all types of educational mismatches in the steady state equilibrium, which accords with the empirical evidence (Daly et al., 2000; Rubb, 2003; Frenette, 2004) on the persistence of overeducation and undereducation.

Proposition 6. *Overeducation and undereducation coexist in a steady state equilibrium. Also, residual wage inequality exists in both the highly educated group as well as the low-educated group.*

Thus far, it is the first model calibration in the existing literature that solely utilizes SBTC to simulate the education premium and the residual

[19] Acemoglu (2001) and Leonardi (2007) build the models with homogeneous workers, thereby generating no overeducation or undereducation. Albrecht and Vroman (2002), Blazquez and Jansen (2008) and Dolado et al. (2009) neglect the incidence of undereducation. Shi (2002) proves that there does not exist any overeducation in the equilibrium.

Figure 6: Correlation: Historical Data and Simulated Result

Table 1. Correlation Between The Simulated Result and The Historical Data in the U.S., 1963-2005

			Simulated Results			
			Education Premium (The High-Tech Vacancy)	Education Premium (The Low-Tech Vacancy)	Residual Wage Inequality (The High-Educated)	Residual Wage Inequality (The Low-Educated)
Historical Data	BPP	Education Premium	0.9036	0.9255		
		Residual Wage Inequality			-0.9486	0.9813
	CID	Education Premium	-0.6016	-0.7061		
		Residual Wage Inequality			0.8297	0.8359
	Total	Education Premium	0.6591	0.9149		
		Residual Wage Inequality			0.3477	0.8501

wage inequality such that (i) the residual wage inequality rises gradually, (ii) the education premium first falls in the 1970s and then rises in the following period, (iii) the education premium has grown at faster speed than the residual wage inequality since the mid-1980s, (iv) the residual wage inequality exists not only in the highly educated group but also in the low-educated group, and (v) a real wage declines in the lower end of the wage distribution since 1960s.

5 Conclusion

This paper analyzes two SBTC effects, biased productivity premium effect and capital intensity dispersion effect. The biased productivity premium improves the average productivity of the highly educated in high-tech vacancies, inducing the education premium to rise. Meanwhile, more sophisticated technology requires high-tech firms to create new vacancies at a higher instalment cost. High-tech firms therefore possess higher capital-labor ratios than before, increasing the returns to the highly educated in the high-tech firms. As a result, the capital intensity dispersion effect causes the wages of the highly educated to be more dispersed amongst firms with different technologies, widening the residual inequality.

This paper contributes to the existing literature by explaining both the education premium and the residual wage inequality solely using SBTC, concluding that SBTC is sufficient to understand the U.S. wage inequality dynamics during 1963-2005. The calibration result explains the puzzle why the residual wage inequality exists amongst the highly educated as well as the low-educated, the residual wage inequality rose gradually during 1963-2005, the education premium fell in the 1970s and rose in the other periods and the education premium grew faster than the residual wage inequality after the early 1980s.

6 Proof

6.1 Proof of Lemma (1)

Proof. Consider $\delta^R_{Hj} < \delta^R_{Lj}$. Differentiating $[1 - F(\delta^R_{ij})]\mathbf{E}(\delta_{ij} - \delta^R_{ij}|\delta_{ij} \geq \delta^R_{ij}) = \int_{\delta^R_{ij}}^{\infty}(x - \delta^R_{ij})f(x)dx$ with respect to δ^R_{ij} using Leibniz integral rule, it is straightforward to show that $[1 - F(\delta_{ij}^R)]\mathbf{E}(\delta_{ij} - \delta_{ij}^R | \delta_{ij} \geq \delta_{ij}^R)$ is decreasing in δ_{ij}^R. Equation (17) and $\delta_{Hj}^R < \delta_{Lj}^R$ imply $J_H^U > J_L^U$. Consider $\delta_{Hj}^R = \delta_{Lj}^R$. $\underline{\mathrm{x}}_H > \underline{\mathrm{x}}_L$ implies $J_H^U > J_L^U$. Consider $\delta_{Hj}^R > \delta_{Lj}^R$. Equation (16) implies $J_H^U > J_L^U$. Hence, we can conclude that $J_H^U > J_L^U$.

Assume $\int_{\delta_{Lb}^R}^{\infty} (P_b x - rJ_L^U - rk) dF_{Lb}(x) < \int_{\delta_{Lg}^R}^{\infty} (P_g x - rJ_L^U - \sigma rk) dF_{Lg}(x)$. $\delta_{Lb}^R < \delta_{Lg}^R$ implies $P_g > P_b$. Suppose $\delta_{Lb}^R \geq \delta_{Lg}^R$. Since $\sigma > 1$, equations (16) imply $P_g > P_b$.

Assume $\int_{\delta_{Lb}^R}^{\infty} (P_b x - rJ_L^U - rk) dF_{Lb}(x) \geq \int_{\delta_{Lg}^R}^{\infty} (P_g x - rJ_L^U - \sigma rk) dF_{Lg}(x)$. Using the equations (18) and (19), $\sigma > 1$ impies $\int_{\delta_{Hg}^R}^{\infty} (P_g x - rJ_H^U - \sigma rk) dF_{Hg}(x) > \int_{\delta_{Hb}^R}^{\infty} (P_b x - rJ_H^U - rk) dF_{Hb}(x)$. $\delta_{Hb}^R < \delta_{Hg}^R$ implies $P_g > P_b$. Using the equations (16), $\delta_{Hg}^R \geq \delta_{Hb}^R$ implies $P_g > P_b$. □

6.2 Proof of the Proposition (1)

Proof. Using wages equation (7), we acquire the wage differentials of the worker in the same industry,

$$w_{Hj}(\delta) - w_{Lj}(\delta) = (1 - \beta)(rJ_H^U - rJ_L^U)$$

Since $rJ_H^U > rJ_L^U$, we can conclude that $w_{Hj}(\delta) > w_{Lj}(\delta),\ \forall \delta > \underline{\mathrm{x}}_H$. Using wage equation (7), we acquire the residual inequality of the worker i,

$$w_{ig}(\delta) - w_{ib}(\delta) = \beta[\delta(P_g - P_b) - (\sigma - 1)rk]$$

Hence, for all $\delta > \max\{\delta_{ib}^R, \delta_{ig}^R\}$, $w_{ib}(\delta) < w_{ig}(\delta)$ iff $\delta > \frac{(\sigma-1)rk}{\beta(P_g^* - P_b^*)}$. □

6.3 Proof of the Proposition (2)

Proof. Using lemma (1) and wage equation (7), we acquire the wage differentials of the worker in the same industry,

$$\begin{aligned} \ln \frac{\mathbf{E}(w_{Hj}(\delta) | \delta \geq \delta_{Hj}^R)}{\mathbf{E}(w_{Lj}(\delta) | \delta \geq \delta_{Lj}^R)} &= \ln \frac{\frac{\beta P_j \int_{\delta_{Hj}^R}^{\infty} \delta_{Hj} - \delta_{Hj}^R dF_{Hj}(\delta_{Hj})}{1 - F_{Hj}(\delta_{Hj}^R)} + rJ_H^U}{\frac{\beta P_j \int_{\delta_{Lj}^R}^{\infty} \delta_{Lj} - \delta_{Lj}^R dF_{Lj}(\delta_{Lj})}{1 - F_{Lj}(\delta_{Lj}^R)} + rJ_L^U} \\ &= \ln \frac{[a - (1 - \beta)]rJ_H^U + \beta rk_j}{[a - (1 - \beta)]rJ_L^U + \beta rk_j} > 0 \end{aligned}$$

Education premium arises from the differentials in the outside option values of two education groups. Similarly, residual wage inequality is:

$$\ln \frac{\mathbf{E}(w_{ig}(\delta)|\delta \geq \delta_{ig}^{R})}{\mathbf{E}(w_{ib}(\delta)|\delta \geq \delta_{ib}^{R})} = \ln \frac{[a-(1-\beta)]rJ_i^U + \beta\sigma rk}{[a-(1-\beta)]rJ_i^U + \beta rk} > 0$$

□

References

[1] Abowd, John M., Francis Kramarz, and David N. Margolis. (2002) "Higher wage workers and high wage firms." *Econometrica*, 67: 251-333.

[2] Acemoglu, Daron. (1998) "Why do new technologies complement skills? Directed technical change and wage inequality." *Quarterly Journal of Economics*, 113: 1055-90.

[3] Acemoglu, Daron. (1999) "Changes in unemployment and wage inequality: An alternative theory and some evidence." *American Economic Review*, 89: 1259-78.

[4] Acemoglu, Daron. (2001) "Good jobs versus bad jobs." *Journal of Labor Economics*, 19: 1-21.

[5] Acemoglu, Daron. (2002) "Directed technical change." *Review of Economic Studies*, 69: 781-809.

[6] Acemoglu, Daron. (2003) "Patterns of skill premia." *Review of Economic Studies*, 70: 199-230.

[7] Allen, Steven G. (2001) "Technology and the wage structure." *Journal of Labor Economics*, 19: 440-83.

[8] Autor, David H., Lawrence F. Katz, and Alan B. Krueger. (1998) "Computing Inequality: Have computers changed the labor market?" *Quarterly Journal of Economics*, 113:1169-215.

[9] Autor, David H, Lawrence F. Katz, and Melissa S. Kearney. (2008) "Trends in U.S. wage Inequality: Revising the revisionists." *Review of Economics and Statistics*, 90: 300-23.

[10] Barron, John M. (1975) "Search in the labor market and the duration of unemployment: Some empirical evidence." *American Economic Review*, 65: 934-42.

[11] Bartel, Ann P., and Nachum Sicherman. (1999) "Technological change and wages: An inter-industry analysis." *Journal of Political Economy*, 107: 285-325.

[12] Berman, Eli, John Bound, and Zvi Griliches. (1994) "Changes in the demand for skilled labor within U.S. manufacturing: Evidence from the annual survey of manufactures." *Quarterly Journal of Economics*, 109: 367-97.

[13] Blazquez, Maite, and Marcel Jansen. (2008) "Search, mismatch and unemployment." *European Economic Review*, 52: 498-526.

[14] Bound, John, and George Johnson. (1992) "Changes in the structure of wages in the 1980's: An evaluation of alternative explanations." *American Economic Review*, 82: 371-92.

[15] Card, David, and John E. DiNardo. (2002) "Skill-biased technological change and rising wage inequality: Some problems and puzzles." *Journal of Labor Economics*, 20: 733-83.

[16] Caselli, Francesco. (1999) "Technological revolutions." *American Economic Review*, 89: 78-102.

[17] Chevalier, Arnaud. (2003) "Measuring Over-education." *Economica*, 70: 509-31.

[18] Cohn, Elchanan, and Ying C. Ng. (2000) "Incidence and wage effects of overschooling and underschooling in Hong Kong." *Economics of Education Review*, 19: 159-68.

[19] Cole, Harold L., and Richard Rogerson. (1999) "Can the Mortensen-Pissarides matching model match the business-cycle facts?" *International Economic Review*, 40: 933-59.

[20] Daly, Mary C., Felix Buchel, and Greg J. Duncan. (2000) "Premiums and penalties for surplus and deficit education Evidence from the United States and Germany." *Economics of Education Review*, 19: 169-78.

[21] Davis, Stephen, and John Haltiwanger. (1992) "Gross job creation, gross job destruction, and employment reallocation." *Quarterly Journal of Economics*, 107: 819-63.

[22] DiNardo, John E., Nicole M. Fortin, and Thomas Lemieux. (1996) "Labor market institutions, and the distribution of Wages, 1973-1992: A semiparametric approach." *Econometrica*, 64: 1001-44.

[23] Dolado, Juan J., Marcel Jansen, and Juan F. Jimeno. (2009) "On-the-job search in a matching model with heterogeneous jobs and workers." *Economic Journal*, 119: 200-28.

[24] Frenette, Marc. (2004) "The overqualified Canadian graduate: The role of the academic program in the incidence, persistence, and economic returns to overqualification." *Economics of Education Review*, 23: 29-45.

[25] Gottschalk, Peter. (1997) "Inequality, income growth, and mobility: The basic facts." *Journal of Economic Perspectives*, 11: 21-40.

[26] Jovanovic, Boyan. (1979) "Job matching and the theory of turnover." *Journal of Political Economy*, 87: 972-90.

[27] Juhn, Chinhui, Kevin M. Murphy, and Brooks Pierc. (1993) "Wage inequality and the rise in returns to skill." *Quarterly Journal of Economics*, 101: 410-42.

[28] Katz, Lawrence F., and Kevin M. Murphy. (1992) "Changes in relative wages: Supply and demand factors." *Quarterly Journal of Economics*, 107: 35-78.

[29] Kiker, B.F., Maria C. Santos, and De Oliveira M. Mendes. (1997) "Overeducation and undereducation: Evidence for Portugal." *Economics of Education Review*, 16: 111-25.

[30] Krueger, Alan B. (1993) "How computers have changes the wage structure: Evidence from microdata, 1984-1989." *Quarterly Journal of Economics*, 108: 33-60.

[31] Lemieux, Thomas. (2006) "Increased residual wage inequality: Composition effects, noisy data, or rising demand for skill." *American Economic Review*, 96: 461-98.

[32] Leonardi, Macro. (2007) "Firm heterogeneity in capital-labor ratios and wage inequality." *Economic Journal*, 117: 375-98.

[33] Levy, Frank, and Richard J. Murnane. (1992) "U.S. earnings levels and earnings inequality: A review of recent trends and proposed explanations." *Journal of Economic Literature*, 30: 1333-81.

[34] McGuinness, Seamus, and Jessica Bennett. (2007) "Overeducation in the graduate labour market: A quantile regression approach." *Economics of Education Review*, 26: 521-31.

[35] Merz, Monika. (1995) "Search in the labor market and the real business cycle." *Journal of Monetary Economics*, 36: 269-300.

[36] Pissarides, Christopher A. (1986) "Unemployment and vacancies in Britain." *Economic Policy*, 3: 499-559.

[37] Rubb, Stephen. (2003) "Overeducation: A short or long run phenomenon for individuals?" *Economics of Education Review*, 22: 389-94.

[38] Rumberger, Russell W. (1987) "The impact of surplus schooling on productivity and earnings." *Journal of Human Resources*, 22: 24-50.

[39] Shi, Shouyong. (2002) "A Directed Search Model of Inequality with heterogeneous skills and skill-biased technology." *Review of Economic Studies*, 69: 467-91.

[40] Sicherman. Nachum. (1991) "Overeducation in the Labor Market." *Journal of Labor Economics*, 9: 101-22.

[41] Vahey, Shaun P. (2000) "The great Canadian training robbery: Evidence on the returns to educational mismatch." *Economics of Education Review*, 19: 219-27.

[42] Verdugo, Richard R., and Naomi T. Verdugo. (1989) "The impact of surplus schooling on earnings: Some additional findings." *Journal of Human Resources*, 24: 629-43.

[43] Wong, Linda Y. (2003) "Can the Mortensen-Pissarides model with productivity changes explain U.S. wage inequality?" *Journal of Labor Economics*, 21: 70-105.