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Changes in Relative Ability as a Determinant of the U.S. College Premium

DARIUS D. MARTIN*
American University of Beirut
Beirut, Lebanon

YONGLI ZHANG
Central University of Finance and Economics
Beijing, China

We develop a macroeconomic framework to estimate the importance of fluctuations in relative ability in accounting for trends in the college premium in the United States since 1965. The theoretical scaffolding is a heterogeneous agent model with two dimensions of ability and endogenous schooling choice, with exogenous skill-biased technological change (SBTC), college tuition, and noneconomic social forces. We find that an increase in the social and economic forces that promote college attendance reduce the relative mean ability of college educated workers. We attribute the drop in the college premium over the 1970s to a 25.5% drop in the mean relative quality of college educated workers from 1968 to 1977. We find that SBTC explains about two thirds of the increase in college attendance since 1965, and that absent both supply shifts and a supply response to SBTC, the relative wage of highly educated workers would have been 77.1% larger in 2013.

Keywords: College Premium, Self-Selection, Human Capital

JEL Classification: E24, J23, J24, J31

1 Introduction

Over the past fifty years, the fraction of workers in the United States with a college education has tripled, from about 12% of all workers in 1965 to just under 40% in 2013. Given this huge increase, it is reasonable to suspect that the relative average quality of college educated workers has also changed. In this paper, we investigate how an increase in the social and

*Corresponding author: dm17@aub.edu.lb

economic forces that promote college attendance alters the ability distribution of the college educated workforce. We find that the college premium fell over the 1970s because the relative ability of college educated workers declined with a massive expansion of college education in that decade.

The presence of fluctuations in the ability composition of the pool of college educated workers has received little attention in the literature. This is an important gap because of the salience of ability in determining the college premium[1]. Since ability is unobservable, it is difficult to decompose changing wages into the contributions of skill prices and worker quality empirically. Separating cohort, age, and time effects is subject to identification problems, because each of these variables is a linear combination of the other two. We therefore develop a macroeconomic framework to explicitly model how the segregation of workers by skill into the college educated workforce and its complement responds to skill-biased technological change (SBTC), increased college tuition, and other social forces.

We use a heterogeneous-agent overlapping-generations model with two sectors of production: skilled and unskilled labor. Agents in our model are endowed with two kinds of human capital, which are mental ability and physical strength. These endowments determine an agent's productivity in either sector, and are correlated in the spirit of the Roy selection model. Agents with more mental than physical ability have a comparative advantage in performing skilled labor. At birth, workers irreversibly decide which of these two abilities to optimally supply in the labor market. To work in the skilled sector, it is necessary to first complete four years of college. College attendance is therefore endogenous, and the college premium is the product of the relative price of human capital and the relative mean ability of workers with and without a college education. SBTC and social change increase the quantity of workers who optimally self-select into supplying cognitive skill. We show that this in turn erodes the relative mean ability of college educated workers.

The model is attractive in that it accounts for both the decline in the college premium for young workers which lasted until 1975, and its subsequent increase. This is because there are two countervailing forces. On the one hand, SBTC and social change promote college enrollment, and thus reduce the ability differential favoring college educated workers. On the other hand, SBTC increases the relative demand for college workers. After 1975, demand-driven increases in relative skill prices overwhelm both demand and supply driven declines in relative skill quality, and the college premium begins to rise in the model.

We ultimately attribute the drop in the college premium for young workers in the 1970s to a 25.5% drop in their mean relative quality from 1968 to 1977. This qualitative decline is a result of an increase in college enrollment that is in turn caused by exogenous social change.

[1] According to Juhn et al. (1993), changes in unmeasured prices and quantities account for at least two-thirds of the overall increase in inequality from 1968 to 1988.

We finally run several counterfactual experiments to determine how college enrollment responds to exogenous shocks. We find (i) the economic incentives embedded in SBTC explain about two-thirds of the increase in college attendance since 1965; (ii) if there were no SBTC, then exogenous supply side forces alone would produce a small increase in higher education.

In the next section, we present the data and discuss the research context. The model is presented in Section 3, and parameterized and solved along a transition path in Section 4. We discuss the results and run counterfactual exercises in Section 5. Section 6 concludes with a discussion of areas for further study.

2 Background and Data

Figure 1 plots the college premium since 1965. The college premium for younger workers drops over the 1970s. Sustained growth in the college premium starts in the late 1970s, but slows down in the mid-1990s. The premium for older workers has increased only modestly since 1965, with no drop in the 1970s.

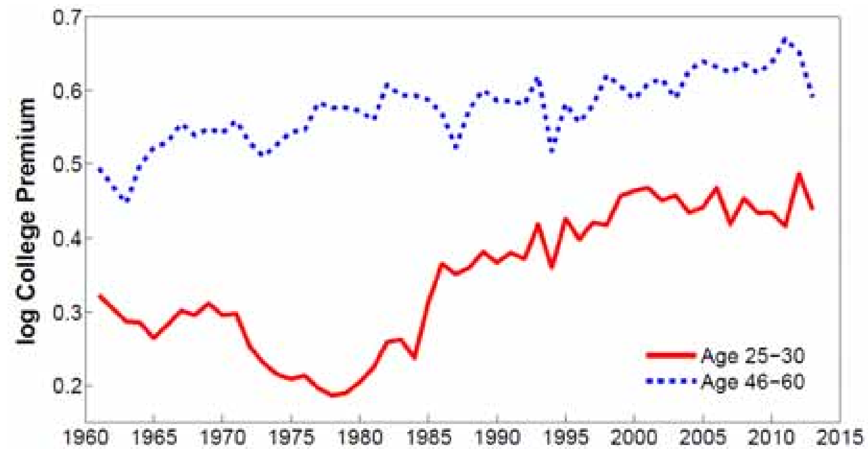
The increasing college premium coincides with a large increase in the proportion of workers with a college education. CPS data indicate that from 1958 to 1970, the fraction of 18-year olds who finished college by age 25 rose from 16.1% to 25.9%. This number declined slightly, to 24.0% in 1974, and has been on a steady upward trend ever since. More recently, 41.0% of 18 year olds in 2007 ultimately completed college by 2014.

Our intention is to untangle the underlying technological and social forces that can explain the behavior of both the college premium and college enrollment. This is complicated because changes in the college premium may reflect either changes in the relative price of highly-skilled human capital, or in the mean relative ability of college-educated workers.

The traditional approach in accounting for the college premium follows Katz and Murphy (1992): they combine a linear trend in skill-biased technological change with fluctuations in relative supply. Katz and Murphy argue that the college premium fell over the 1970s because of a large increase in relative supply. But since supplies are exogenous, this framework does not explain the increase in college attendance during the 1980s – an increase that followed a decade of a declining college premium. Moreover, since supplies are measured as the number of workers with and without a college education, this approach implicitly assumes that an increase in the proportion of workers who obtain a college education will occur without a qualitative change in the college educated workforce. So in our alternative approach, we endogenize supplies and measure them in units of human capital.

Macroeconomic research on the college premium has largely focused on the demand side, and especially on the nature of technological change. In Krussel et al. (2000), capital-skill complementarity is the demand-side factor driving the skill premium: if educated workers are

Figure 1: The College Premium



more complementary with capital than unskilled workers, then technological improvements which increase the capital stock also increase the college premium. In Acemoglu (1998) an exogenous increase in the supply of skills depresses the relative wage in the short run, but raises it in the long run by incentivizing the invention of skill-complementary technologies. Finally, in Greenwood and Yorukoglu (1997), college educated workers are needed to adopt new technologies, and the rising college premium is due to the diffusion of new technologies associated with the information technology revolution that began in 1974. These models all abstract from individual heterogeneity.

Papers from a smaller literature that endogenizes the supply of college graduates in an environment with heterogeneous agents include Guvenen and Kuruscu (2012) and Heckman, Lochner, and Taber (1998). Our paper differs from these in a few important ways. The other two papers both highlight differential on-the-job investment in human capital by high and low skilled workers. In these models, the college premium falls in the 1970s because college workers increase their investment time more than non-college workers with the onset of SBTC. We focus on an altogether different channel.

The other two papers also both use a Ben-Porath human capital accumulation model[2]. We adapt the Roy model of sectoral choice; our paper uniquely emphasizes the multi-dimensionality of ability in a macroeconomic environment. Guvenen and Kuruscu also use two factors, which they call raw labor and human capital. But in their model there is only heterogeneity in the ability to accumulate human capital[3]. As we show in Section 3.4 below,

[2] See Ben-Porath (1967)

[3] While their companion paper Guvenen and Kuruscu (2010) allows for heterogeneity in both raw labor and ability, the two factors are drawn from uniform, perfectly correlated distributions.

two-dimensional heterogeneity, and especially the correlation between the distributions of the endowments of the two factors, are important concepts for interpreting the ability channel that we study here.

The presence of multiple dimensions of ability is consistent with empirical evidence that most variation in job characteristics can be explained by variation in a small number of factors. For example, Abraham and Spletzer (2009) examine the Standard Occupation Classification system used in the Occupational Employment Statistics Survey, and find that there are three dimensions of ability: analytical, interpersonal, and physical skills. Ingram and Neuman (2006) reach similar conclusions from an analysis of the US Dictionary of Occupational Titles.

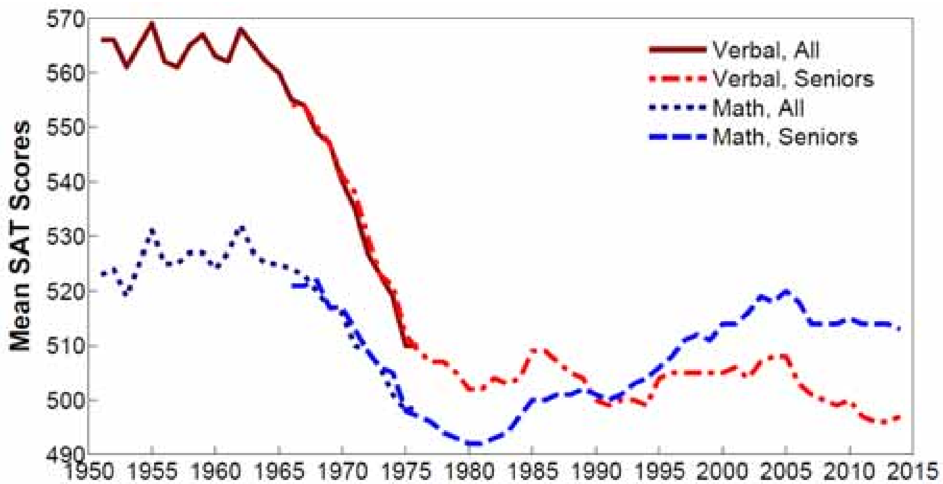
Our model descends from the canonical self-selection model of Borjas (1987). In that paper the author uses a Roy model to show how characteristics of the income distribution in a foreign country affects the quality of that country's emigrants to the United States. He then attributes observed differences in immigrant quality across countries to cross-country differences in these characteristics. While Borjas investigates immigration to the United States, we investigate college enrollment. In order to explain trends in both college enrollment and the college premium, we incorporate ideas from the Borjas self-selection model into life cycle model with endogenous wages.

To study the relationship between college education and cohort quality it would be natural to use test scores as noisy indicators of ability. Taubman and Wales (1972) report on a variety of IQ tests administered to high school seniors from 1925 to 1965, and conclude that the expansion of college enrollment at that time was associated with an increase in the ability of college educated people. Until 1965, the most able high-school graduates became more likely to attend college. Juhn et al. (2005) argue that this relationship has reversed since 1965, so that the share of a cohort with a college education is negatively correlated with the average quality of that cohort's college graduates. This is in line with our results.

In Figure 2, we plot average scores on the SAT test. From 1963 to 1980, the mean score on the verbal section of the SAT of high school seniors intending to go to college, or "college-bound seniors", fell 10.4%. The mean math score fell 5.4%. In their report, Wirtz et al. (1977) present evidence that this decline is understated by 8 to 10 points since the SAT in the 1970s was easier than the 1963 SAT. They argue that most of the drop in SAT scores is due to an increase in the proportion of young people who chose to take the SAT. Since the SAT is used for college admission, this is consistent with our argument. The average score fell because a larger number of lower-ability students intended to enroll in college.

The SAT scores remain around lower levels after 1980. This does not necessarily imply that the college premium should also remain lower after 1980, if we assume that SAT scores measure productivity. Recall that while changes in supply reduce the relative aptitude of college educated workers, skill-biased technological change increases their relative demand.

Figure 2: Mean SAT Scores



After 1980, the ability gap stops narrowing, and continuing SBTC results in a higher college premium.

Castro and Coen-Pirani (2014) show that this decline in test scores is not unique to the SAT, but is present in a large number of tests. They attribute this to cohort-level changes in ability, rather than to a within-cohort change in the characteristics of students who continued on to college. Note however that test scores do not measure physical ability. If we assume that physical ability did not change across cohorts, the decline in test scores is consistent with the ability channel hypothesis whether that decline was driven by changes across or within cohorts.

3 The Model

We use a generalized Roy (1951) model of sectoral choice. There are two sectors, and a continuum of heterogeneous agents endowed with two skills. All agents share the same distribution of skills, and each skill is useful in only one sector. Two sectors are necessary to incorporate skill-biased technological change.

We extend the Roy model in two ways. First, we endogenize wages in order to study how the supplies respond to SBTC. Second, we build in a life cycle. Each agent lives many years, and at birth irreversibly selects the one sector in which he or she will work throughout his or her life.

3.1 Production

The factors of production are skilled (type-h) and unskilled (type-l) human capital. There is a competitive, representative firm with a CES production function:

$$Y_t = \left\{\left[\alpha_{h,t} N_{h,t}\right]^{\psi} + \left[\alpha_{l,t} N_{l,t}\right]^{\psi}\right\}^{\frac{1}{\psi}} \tag{1}$$

Y_t is production per worker in year t. $N_{h,t}$ and $N_{l,t}$ are the year t per-worker supplies of both types of human capital. Since the production function exhibits constant returns, it is sufficient to restrict our attention to per-worker quantities. The elasticity of substitution between the two types of skill is $\frac{1}{1-\psi}$. $\alpha_{s,t}$ represents the state of technology favoring workers in sector $s \in \{h, l\}$, so SBTC is an increase in $\frac{\alpha_{h,t}}{\alpha_{l,t}}$. We will frequently use s to denote one of the two sectors.

Sectoral wages $w_{s,t}$ are compensation from the representative firm for each unit of human capital supplied. The equilibrium wages are the marginal products in equation (1):

$$w_{s,t} = \left(\alpha_{s,t}\right)^{\psi}\left(N_{s,t}\right)^{\psi-1}\left\{\left[\alpha_{h,t} N_{h,t}\right] + \left[\alpha_{l,t} N_{l,t}\right]\right\}^{\frac{1}{\psi}-1} \tag{2}$$

Let γ be the long-run rate of neutral technological progress, and let $\widehat{w}_{\mathrm{s,t}}$ be the wage in sector s, normalized for technological advance as follows: $\widehat{w}_{\mathrm{s,t}} = \frac{w_{\mathrm{s,t}}}{\gamma^{\mathrm{t}}}$. Normalized output $\widehat{Y}_{\mathrm{s,t}}$ and factor specific technology $\widehat{\alpha}_{\mathrm{s,t}}$ are defined similarly. Because they are of roughly the same magnitude across time, we work with normalized quantities in what follows.

3.2 Households

The economy consists of an infinite stream of overlapping generations. Each cohort is a continuum of heterogeneous agents distinguished by their log skill endowments $Z = (Z_l, Z_h)$. The skill endowments represent an agent's ability to supply skilled and unskilled labor. The distribution of log skill at birth is Gaussian, and is constant across time: the distribution of ability is the same for all generations. We denote the joint density function of the skill distribution $\phi_2(Z_l, Z_h; \nu)$, with parameters $\nu = (\mu_l, \mu_h, \sigma_l, \sigma_h, \rho)$.

At birth, each agent observes her skill endowments, and then selects her sector of employment. This decision is permanent and irreversible. If an agent chooses the unskilled sector, then she works full-time in sector-l only for every period of life. If instead the agent selects the skilled sector, then she must first attend college for four years before starting to work. Sectoral choice is therefore also a college attendance decision.

Agents can work for a maximum of 47 periods; an agent enters the labor force at age 18, and exits at age 64. The entering cohort at time t corresponds to the 18-year old population, and is of mass n_t. For convenience, in this paper "an i-year old" agent actually refers to someone aged 18+ i, and an agent "born" at time t is really 18 years old at t. Similarly, "agent $Z_{s,i}$" refers to an i-year old agent who works in sector s with ability Z_s. Finally, it is convenient to define $T = 46$, so an agent who enters the labor force at time t exits at the end of time $t + T$

Of all agents born at time t, a fraction $\pi_{i,t+i}$ remain in the workforce after i periods. The survival probabilities are exogenous, and $\pi_{0,t} = 1$. Cohort i's share of the time t workforce $\eta_{i,t}$ is therefore:

$$\eta_{i,t} = \frac{\pi_{i,t} n_{t-i}}{\sum_{j=0}^{T} \pi_{j,t} n_{t-j}}, \quad 0 \leq i \leq T$$

Agent $Z_{s,i}$'s log human capital is $Z_{s,i} + h_{s,i}$, where $h_{s,i}$ captures the accumulation of human capital over the life-cycle. In the standard Mincer equation[4], log earnings are quadratic in potential experience, since human capital rises with experience, but depreciates with age. However, Lemieux (2006) and Murphy and Welch (1990) argue that the quadratic specification significantly understates earnings growth in the first ten years in the labor market, and overstates the decline in late career earnings by about 33%. With a quartic specification, the bias nearly disappears. Thus, in this paper $h_{s,i}$ is a quartic in experience, with a vector of coefficients β_s. Note that since agents work every period until they permanently leave the labor force, experience equals age in sector l. Because college completion is a prerequisite to working sector h, experience in sector h is $i - 4$.

Sectoral choice depends on expected discounted income in both sectors, the discounted value of all (normalized) tuition expenses τ_t and an exogenous cohort effect x_t. The cohort effect is intended to capture all social and institutional forces that influence college attendance. Among other things, this includes changes in government subsidies and loan programs, fluctuations in the psychic costs of college, in the social status accruing to college graduation, in the capacity of colleges to enroll students, and in military conscription policies[5]. Cohort-specific effects are often included as birth-year cohort dummies in empirical studies of the college premium[6].

Expected discounted lifetime income for an agent born at time t with ability Z_s is $V_{s,t}\exp(Z_s)$, where

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[4] See Mincer (1974)

[5] In the late 1960s, enrollment in college allowed young men to avoid military conscription. Card and Lemieux (2001b) estimate that draft avoidance increased the fraction of men with a college degree by about 2 percentage points.

[6] For example, see Juhn et al. (2005).

$$V_{s,t} = \sum_{i=0}^{T} \left(\frac{\gamma}{R}\right)^{t} \pi_{i,t+i} E\left[\widehat{w}_{s,t+i}\right] \exp\left(h_{s,i}\right) \tag{3}$$

R is the (exogenous) gross return on savings, and γ is again the long run trend in per-capita income. $\mathrm{E}\left[\widehat{w}_{s,t+i}\right]$ is the normalized price of type-s skill that is expected to prevail at time t+i in time t.

Agents form expectations over the future paths of the exogenous variables: the cohort effect, tuition, and the parameters that govern SBTC. Given these expectations, the expected future prices are market-clearing. For simplicity, rather than specifying an underlying stochastic process governing the evolution of the exogenous variables, we specify how expectations are formed, given their current values.

We solve the model under two different assumptions concerning expectations formation: perfect foresight, and static expectations. Under perfect foresight, expectations coincide with the true path of the exogenous variables. Under static expectations, agents expect the current values of the technology parameters, tuition, and the cohort effect to remain unchanged into the infinite future. Since we cannot ourselves forecast future technological change, we do not consider perfect foresight to be especially credible. For that reason, in our benchmark model for which we report the most detailed results, we assume that agents have static expectations.

These two extreme cases capture the range of possible outcomes that can be generated by the model. The model can also be used to analyze an intermediate case where workers receive a noisy signal about the trend in some or all of the exogenous variables. One possibility is for agents to be aware of the final balanced growth path, and expect the technology parameters to converge there at a given rate over a fixed future period. However because the results are similar in their key respects under perfect foresight and static expectations, we confine our attention to these two extremes.

An agent will attend college if the net benefit of college attendance is positive: if $V_{h,t}\exp(Z_h) + x_t - \tau_t > V_{l,t}\exp(Z_l)$. Letting $s_t(Z)$ indicate sectoral choice, we have

$$s_t(Z) = \begin{cases} h & \text{if } Z_h \geq c_{l,t}(Z_l) \\ l & \text{otherwise} \end{cases} \tag{4}$$

where $c_{l,t}(Z_l)$ is the cutoff endowment of log high-skilled human capital necessary for college enrollment given Z_l:

$$c_{l,t}(Z_l) = log\left[\tau_t - x_t + exp(Z_l)V_{l,t}\right] - log\left(V_{h,t}\right) \tag{5}$$

In order to write the per-worker factor supplies $N_{s,t}$, we introduce some notation. First, let $c_{h,t}(Z_h) = c_{l,t}^{-1}(Z_h)$, where the inverse exists. Let $d_{s,t}$ be the lower bound on the domain of $c_{s,t}(Z_s)$, so for example:

$$d_{l,t} = \begin{cases} log(x_t - \tau_t) - log(V_{l,t}) & if\ x_t > \tau_t \\ -\infty & otherwise \end{cases}$$

Now in each sector, the per-worker factor supplies are the weighted sum of the per-worker supplies of each cohort. The weights are the cohort shares.

$$N_{l,t} = \sum_{i=0}^{T} \eta_{i,t} \exp(h_{l,i}) \int_{d_{l,t-i}}^{\infty} \int_{-\infty}^{c_{l,t-i}(Z_l)} \exp(Z_l) \phi_2(Z_l, Z_h; \upsilon) dZ_h dZ_l \tag{6}$$

$$N_{h,t} = \sum_{i=4}^{T} \eta_{i,t} \exp(h_{h,i}) \int_{d_{h,t-i}}^{\infty} \int_{-\infty}^{c_{h,t-i}(Z_h)} \exp(Z_h) \phi_2(Z_l, Z_h; \upsilon) dZ_l dZ_h \tag{7}$$

3.3 Equilibrium at time *t*

Given the initial conditions $s_{t-k}(Z)$ for $1 \le k \le T$ and the exogenous variables representing current and expected future

1. Technology: $\hat{\alpha}_{s,t+k},\ k \ge 0, s \in \{h, l\}$
2. Cohort Sizes: $n_{t+k},\ k \ge -T$
3. Survival Probabilities: $\pi_{i,t+k},\ 0 \le i \le T,\ k \ge 0$
4. Cohort Effects: $x_t, t \ge 0$
5. Tuition: $\tau_t, t \ge 0$

an equilibrium at time t consists of sequences of current and expected future wages, human capital supplies $N_{h,t+k}$, and $N_{l,t+k}$ for $k \ge 0$, and schooling decision rules $s_{t+k}: \mathbb{R}^2 \to \{l, h\}$ for $k \ge 0$, such that

1. Schooling decisions satisfy equation 4.
2. The equilibrium human capital quantities are given by (6), and maximize period profit for the firm given the wages.
3. Expected wages are market clearing.

To enable calibration, we also assume that at $t = 0$ the economy lies along a balanced growth path (BGP). A BGP occurs if the normalized technology parameters, survival probabilities, the cohort growth rate, tuition, and cohort effects are constant for all t: $\hat{\alpha}_{s,t} = \hat{\alpha}_s, \pi_{i,t} = \pi_i, n_{t+1} = \gamma_N n_t, \tau_t = \tau,$ and $x_t = x$.

Following Auerbach and Kotlikoff (1987), at $t = 1$ there is an initial change in all the exogenous variables. In each period, agents calculate the new sequence of expected future equilibrium wages and adjust their behavior accordingly. The economy returns to the BGP quantities after a 150 year transition. The transition begins by assumption in 1965, before the onset of SBTC.

Details about our computational routine for solving for equilibrium endogenous quantities along both the BGP and the transition path are presented in Appendix C. In the next section, we describe the characteristics of the balanced growth path.

3.4 The Balanced Growth Path

Along a BGP, normalized wages are constant: $\hat{w}_{l,t} = \hat{w}_l$ and $\hat{w}_{h,t} = \hat{w}_h$. To see this, note that with constant expected wages, decisions are stationary: in equation 4, we get $c_{l,t}(Z_l) = c_l(Z_l)$, so $s_t(Z) = s(Z)$. This implies that human capital supplies are constant (see equation 6), so wages are unchanging.

We get some intuition about the ability channel by comparing steady states in the special case where $\tau_t = x_t = 0$. This is equivalent to a simpler model where economic forces alone drive the decision to enroll in college, and the cost of college attendance is only forgone income in sector l. Note that we only impose this simplification in this section, to allow a theoretical analysis of the model. We do not set $\tau_t = x_t$ in the quantitative experiments in Sections 5.2 and 5.3.

Moreover, although the following discussion necessarily focuses on SBTC, the same intuition can rationalize the consequences of any exogenous change that favors college enrollment.

Since $\tau_t = x_t = 0$ implies that the cutoff function (equation 5) is linear, we can derive analytical expressions for the mean log ability of workers in both sectors. Recall that the distribution of log ability $Z = (Z_l, Z_h)$ is Gaussian with parameters $(\mu_l, \mu_h, \sigma_l, \sigma_h, \rho)$. Then,

$$E[Z_l \mid s = l] = \mu_l + \frac{\sigma_l \sigma_h}{\sigma_v}\left[\frac{\sigma_l}{\sigma_h} - \rho\right]\lambda(-g) \tag{8}$$

$$E[Z_h \mid s = h] = \mu_h + \frac{\sigma_l \sigma_h}{\sigma_v}\left[\frac{\sigma_h}{\sigma_l} - \rho\right]\lambda(g) \tag{9}$$

where

$$\lambda(x) = \frac{\phi(x)}{1 - \Phi(x)}, \qquad \sigma_v = \sqrt{\sigma_h^2 + \sigma_l^2 - 2\rho\sigma_h\sigma_l}, \qquad g \equiv \frac{1}{\sigma_v}\left[\mu_l - \mu_h + log\left(\frac{V_l}{V_h}\right)\right]$$

V_h and V_l were defined in equation 3, and represent discounted lifetime income on the BGP in either sector per unit of human capital.

Equations 8 and 9 show that the average worker in either sector may be more or less able than the population average depending on whether ρ is greater or less than σ_h/σ_l. Let

$k = \min\left\{\frac{\sigma_h}{\sigma_l}, \frac{\sigma_l}{\sigma_h}\right\}$. As in Borjas (1987), there are three cases to consider:

1. *Sorting*: $\rho < k$. In this case, $\mathrm{E}[Z_h \mid s = h] > \mu_h$ and $\mathrm{E}[Z_l \mid s = l] > \mu_l$. The smartest agents supply mental ability, and the strongest agents supply physical ability. Intuitively, a low correlation between the two dimensions of ability allows for a sharper segregation of workers into the two sectors. An agent who is poorly endowed in one dimension of skill is not unlikely to be well endowed in the other.

2. *Positive Selection*: $\rho > k$ and $\sigma_h > \sigma_l$. In this situation, $\mathrm{E}[Z_h \mid s = h] > \mu_h$ and $\mathrm{E}[Z_l \mid s = l] < \mu_l$. Workers who self-select into college are above average in both mental and physical ability. To understand this, consider a worker who is especially physically able. Because ρ is high, the worker is also likely to be mentally able. Moreover, $\sigma_h > \sigma_l$ implies that the upper tail of distribution of mental ability is larger. The worker's mental ability is therefore more likely to be high enough relative to physical ability that the worker optimally attends college.

3. *Negative Selection:* $\rho > k$ and $\sigma_h < \sigma_l$. In this, perhaps unlikely, situation, college attracts the people who are the least adept in both types of labor.

Because SBTC raises the productivity of skilled workers, we can expect SBTC to increase w_h/w_l. Along the BGP, V_h/V_l is proportional to the wage ratio, so SBTC will increase g in equations (8) and (9). Moreover, because $\lambda(x) = \mathrm{E}[z \mid z > x]$, where z follows a standard normal distribution, we can see that λ is an increasing function.

SBTC will therefore lower the ability of college workers, and raise the ability of high school educated workers only under sorting. In this case, SBTC will push workers into sector h, and these workers' abilities in both sectors are on average lower than both sectoral means. The marginal workers are neither the strongest (who remain in sector l), nor the smartest (who already were in sector h). The difference between the mean log ability of workers in sectors h and l falls, narrowing the college premium.

Alternatively under positive selection, SBTC reduces the mean level of ability in both sectors. In this case, the workers who are the smartest are also the strongest, and these workers attend college. Marginal workers who SBTC induces to shift into sector h are less smart than incumbents in sector h, but are stronger than those who remain in sector l. The college premium will fall provided that the quality pool of skilled workers is disproportionately reduced. Finally, in the unlikely case of negative selection, SBTC increases the mean level of ability in both sectors.

Note that in no case does SBTC unambiguously lead to an increase in the college premium. Note also that we describe agents as "shifting" between sectors only to convey the intuition. Agents do not literally shift between sectors. Rather, two agents with the same abilities would select different sectors in BGP equilibria before and after SBTC occurs.

4 Identifying the Parameters

All the parameters in the model are either set externally, identified by maximum likelihood along the initial balanced growth path, or identified by internal calibration along the lines of Katz and Murphy (1992), or Heathcote et al. (2008), among others.

We identify the coefficients for skill distribution and experience μ_l, μ_h, σ_l, σ_h, ρ and β, by maximum likelihood using data drawn from March Current Population Surveys conducted in the 1960s, along the assumed initial balanced growth path. The cohort effect x_t is set to match college completion along the transition path. Finally, $\hat{\alpha}_{l,t}$ and $\hat{\alpha}_{h,t}$ match the mean income of young high school graduates and college graduates along the transition path.

4.1 Parameters set externally

The value $\gamma = 0.01$ approximately matches per-capita output growth from 1947 to the present, according to the National Income and Product Accounts. We set $R = 1.038$, which implies a subjective discount rate of about 0.97. We set $\psi = 0.306$, which implies that the elasticity of substitution between high and low skilled human capital is 1.44. This is consistent with evidence reported in Heckman, Lochner, and Taber (1998), and in Acemoglu and Autor (2012).

Current and future cohort sizes n_t and survival probabilities $\pi_{i,t}$ are taken from the U.S. Census Bureau population estimates and population projections. τ_t is cost of the four years of college from period t to $t + 3$, discounted using $R = 1.038$. Tuition data come from the U.S. Department of Education. See Appendix A for more details.

4.2 Skill Distribution Parameters

Along the initial BGP, we normalize $\hat{\alpha}_l = 1$. Since it is not possible to separate the average ability of workers from their productivity, $\hat{\alpha}_h$ is not identified, and is set arbitrarily to 0.05. The skill distribution and accumulation parameters υ and β maximize the likelihood function. We derive the likelihood function in Appendix B.

The data are drawn from March Current Population Surveys conducted in the 1960s. We set the parameters using data from the 1965 survey, which covers earnings in 1964. To confirm that our estimates are not too sensitive to using the 1964 data, we also estimate the parameters using survey data for each available year before 1969. We use the parameters from the 1965 CPS because these values were for the most part between those calculated using data from the 1962 and 1964 surveys.

We use data from the 1960s to estimate the skill distribution and accumulation parameters because these parameters can only be identified by maximum likelihood along a BGP. To calculate the likelihood of a given trial set of parameters, it is necessary to solve for

Table 1: Skill Distribution Parameters

Parameter	Value	Minimum	Maximum
μ_h	4.6313	4.3011	5.0380
μ_l	5.3043	5.2881	5.3382
σ_l	0.4610	0.4610	0.5499
σ_h	0.4401	0.4398	0.4663
ρ	0.8147	0.6775	0.8707

Table 2: Skill Accumulation Parameters

Parameter	Value	Minimum	Maximum
$\beta_{l,1}$	0.0909	0.0832	0.0909
$\beta_{l,2}$	-0.0052	-0.0052	-0.0048
$\beta_{l,3}$	1.25×10^{-4}	9.85×10^{-5}	1.25×10^{-4}
$\beta_{l,4}$	-1.15×10^{-6}	-1.15×10^{-6}	-8.01×10^{-7}
$\beta_{h,1}$	0.0798	0.0745	0.1123
$\beta_{h,2}$	-0.0037	-0.0065	-0.0025
$\beta_{h,3}$	6.21×10^{-5}	6.53×10^{-6}	1.42×10^{-4}
$\beta_{h,4}$	-2.66×10^{-7}	-1.02×10^{-6}	4.05×10^{-7}

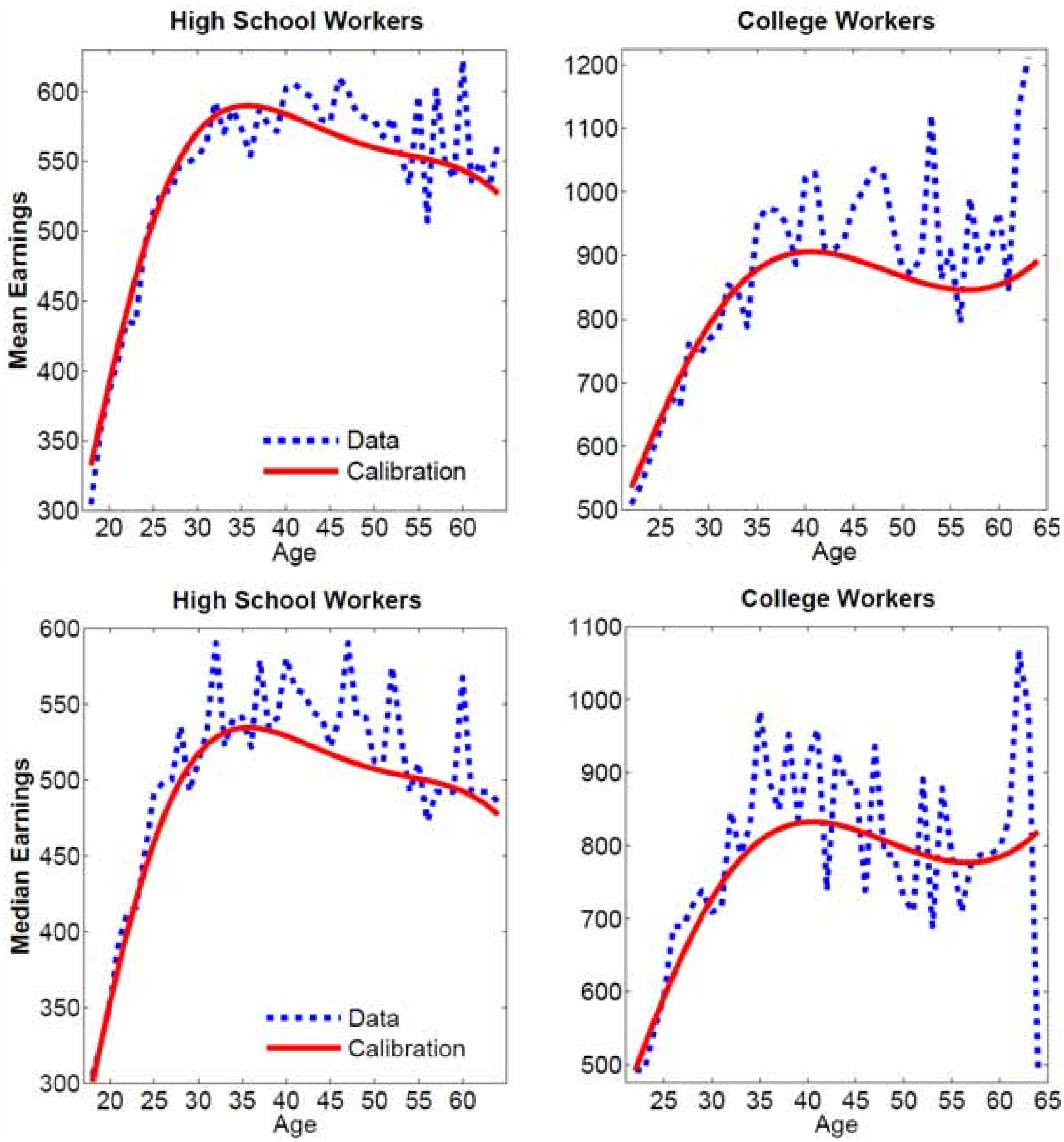
equilibrium wages. Along the transition path, this takes too long for a numerical optimization method to be practical.

Our parameterization, and the range of estimated values from each pre-1969 CPS, are presented in Tables 1 and 2. To check the calibration, Figure 3 plots the data and calibrated values of the mean and median real weekly income within each age group on the initial BGP. Note that the results are consistent with sorting, indicating that the relative mean ability of skilled workers should decay with SBTC when $x = \tau$.

4.3 Identifying the sequences $\hat{\alpha}_{h,t}$, $\hat{\alpha}_{l,t}$, and x_t

We set these exogenous sequences internally to match the median income and education of young workers. Our quantitative experiment is therefore similar to an accounting exercise, allowing us to decompose fluctuations in the college premium into changes in technology and cohort effects. $\hat{\alpha}_{l,t}$ is set to grow 2.6% annually from 1965 to 1972, to drop -1.1% from 1973 to 1995, to grow at 1% from 1995 to 2001, and 0.2% from 2002 to 2013. The model then approximately matches mean income of young high school workers. Given $\hat{\alpha}_{l,t}$, for each period from 1965 to 2013, we first set $\hat{\alpha}_{h,t} = \hat{\alpha}_{h,t-1}$. Next, for periods from 1965 to 2006, we adjust x_t until equilibrium school enrollment for the entering cohort in the model matches the

Figure 3: Real Weekly Income by Age in 1964; Data and Calibration



fraction of workers in that cohort who finished four years of college by age 25. Then in an outer loop, we adjust $\hat{\alpha}_{h,t}$ so that the mean income of young college workers in the model approximately matches the data. The recovered series for technology and cohort effects are presented with our results in Section 5.

5 Results

The mean earnings for young workers in the model and data are plotted in Figure 4. The fraction of workers in each generation who choose sector *h* is graphed in Figure 5. In the data this is the percentage of workers who had finished four years of college by age 25. Note that the model produces a sharp increase in college graduation from 1964 to 1965. This is due to our assumption that the BGP abruptly ends in 1964, and that agents immediately update their expectations.

Table 3 reports the evolution over time of the college premium for young and old workers from 1965 to 2010. We normalize empirical statistics and counterparts in the model to 0 in 1965. We include the simulated statistics under static expectations (SE), and under perfect foresight (PF). Note that in both the model and the data, the college premium declines over the 1970s for young workers only. The college premium for older workers is not directly targeted in our estimation.

Table 3: Cumulative Change in the College Premium since 1965

	Young Workers			Old Workers		
Year	Data	SE	PF	Data	SE	PF
1965	0.0	0.0	0.0	0.0	0.0	0.0
1970	3.1	0.4	-0.1	2.0	0.4	-0.2
1975	-5.6	-8.9	-25.2	2.2	9.9	1.9
1980	-6.0	-11.9	-39.6	5.1	20.0	6.2
1985	4.9	2.2	-22.9	6.6	24.9	8.7
1990	10.2	10.2	-10.9	6.4	28.0	11.1
1995	16.1	14.6	-2.4	6.0	21.9	2.9
2000	19.9	16.3	1.8	6.6	11.7	-11.1
2005	17.6	14.9	4.4	11.7	3.1	-19.7
2010	16.4	8.3	1.4	11.7	1.0	-18.5

The model predicts a much larger increase in the college premium for older workers from 1970 to 1995 than actually occurred. This is driven by a 32.2% increase in relative wage of college workers in the model over that period. The dynamics of college premia for workers in different age groups therefore suggest that older and younger workers are not perfectly substitutable. It would be interesting to generalize our model by introducing imperfect substitutability between workers with different levels of experience[7].

Note that under perfect foresight, there is a much larger decline in the college premium, which lasts under 1995. Intuitively, the supply response to SBTC is amplified if agents in the 1960s and 70s had correctly anticipated the extent of future skill-biased technological change.

[7] Card and Lemieux (2001a) extend the Katz and Murphy framework this way.

Figure 4: Mean Real Income at Age 25-30 in the Model and Data

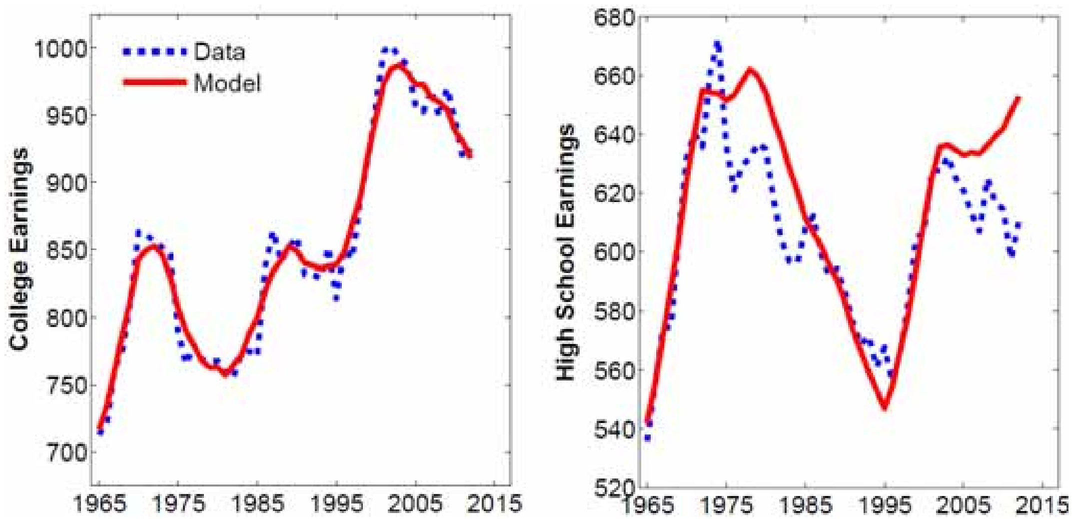
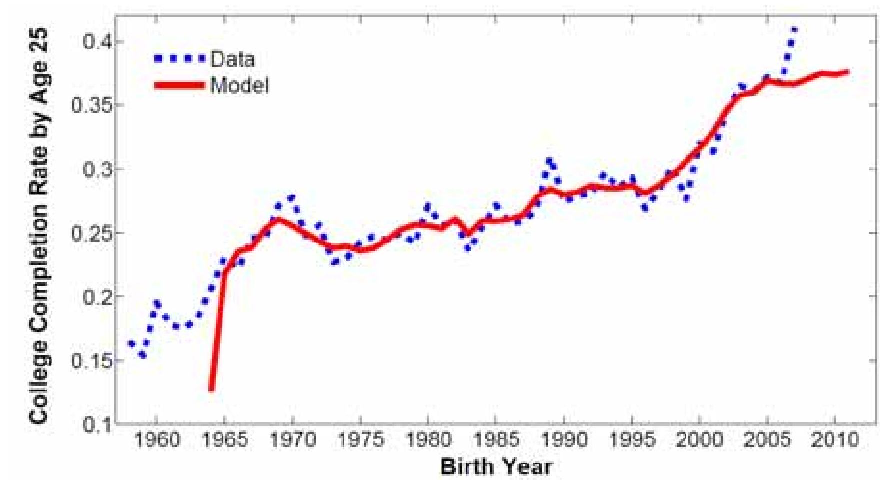
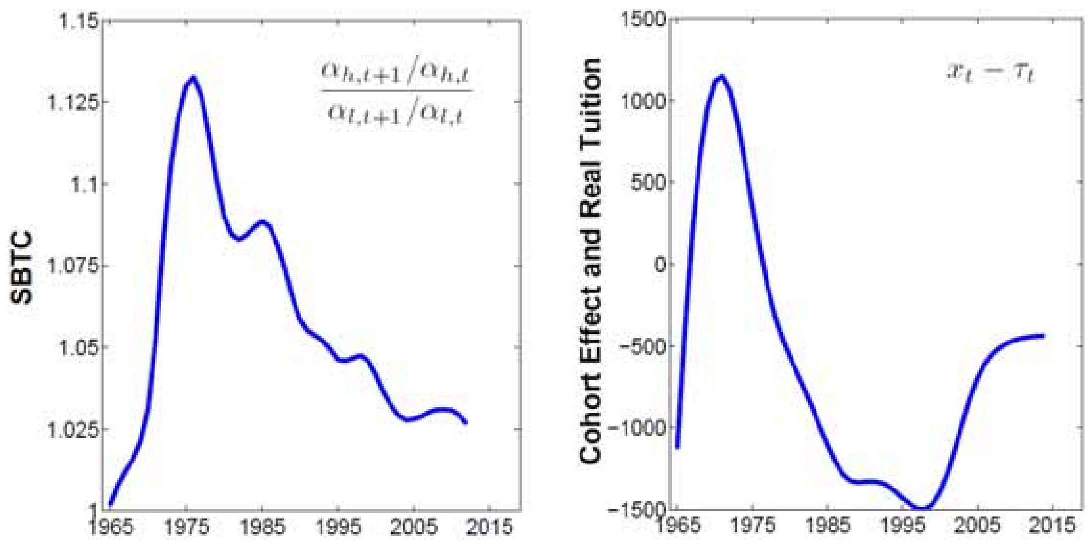


Figure 5: College Completion in the Model and Data



A much greater proportion of young agents would have chosen to go to college, which would cause a larger decline in the relative ability of college-educated workers. Note also that the college premium for older workers rises less in the 1970s and 80s under perfect foresight. This is because the larger shift in the relative supply of college-educated workers produces a smaller increase in the relative price of mental ability.

Figure 6: SBTC, Tuition, and the Cohort Effect along the Transition Path



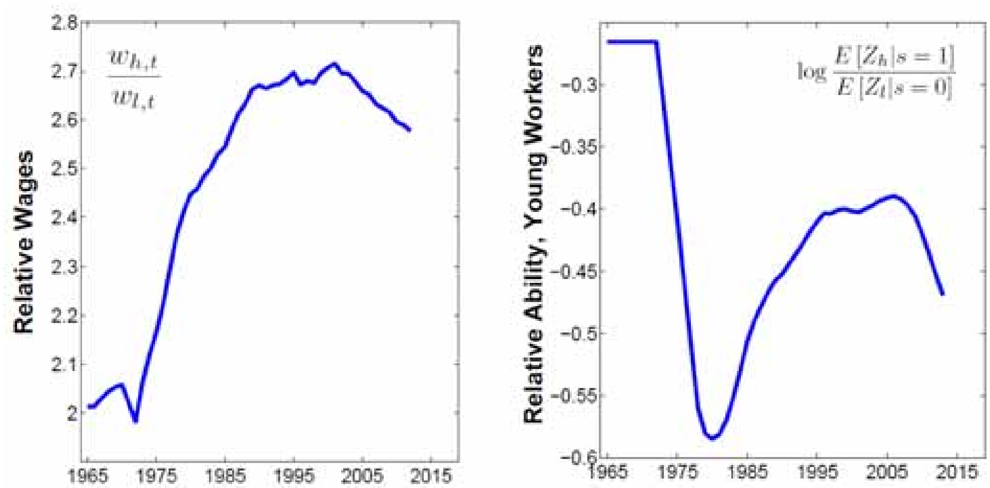
The exogenous sequences that generate these results are the cohort effect, real tuition, and SBTC. They are graphed in Figure 6. Rapid 7.5% to 10% SBTC occurred from the mid-1970s to the late 1980s. This coincides with the introduction of the PC and computerization. SBTC has continued, but decelerated, ever since.

The sharp rise in SBTC in the early 1970s might be the model capturing the diffusion of a new general purpose technology which first became available at that time. According to Greenwood and Yorukoglu (1997) and Magalhaes and Hellstrom (2013), skilled workers were in high demand in the early 1970s, because they were needed to implement the IT revolution. After a learning period, as systems evolved toward standard interfaces, technological change became less skill-biased.

Recall that the cohort effect measures the social pressures which encourage college attendance. Figure 6 shows that the cohort effect surged relative to tuition from the late 1960s through the early 1970s. Acemoglu (1998) also argues that the increase in college enrollment in this period was exogenous, and not a response to higher anticipated returns to college[8]. He identifies the exogenous forces as Vietnam war draft laws, and rising government financial aid for college. The steady decline in exogenous forces from 1975 to 1995 is due to rising college tuition. The increase starting in 1996 may reflect changes in the higher education industry, such as the expansion of for-profit universities.

[8] Acemoglu (1998) reports that total federal aid for college rose from \$2 billion in 1963 to \$24 billion in 1975.

Figure 7: Relative Wages and Skill Levels along the Transition Path



Relative wages and skill levels in the model are graphed in Figure 7. The relative ability of college workers is initially constant because until 1969 college attendance decisions were made under the initial balanced growth path. The relative ability of college workers fell 25.5% from 1970 until 1977. During this same period, relative wages rose 15%. According to the model the drop in the college premium over the 1970s is therefore due entirely to changes in the composition of college educated workers.

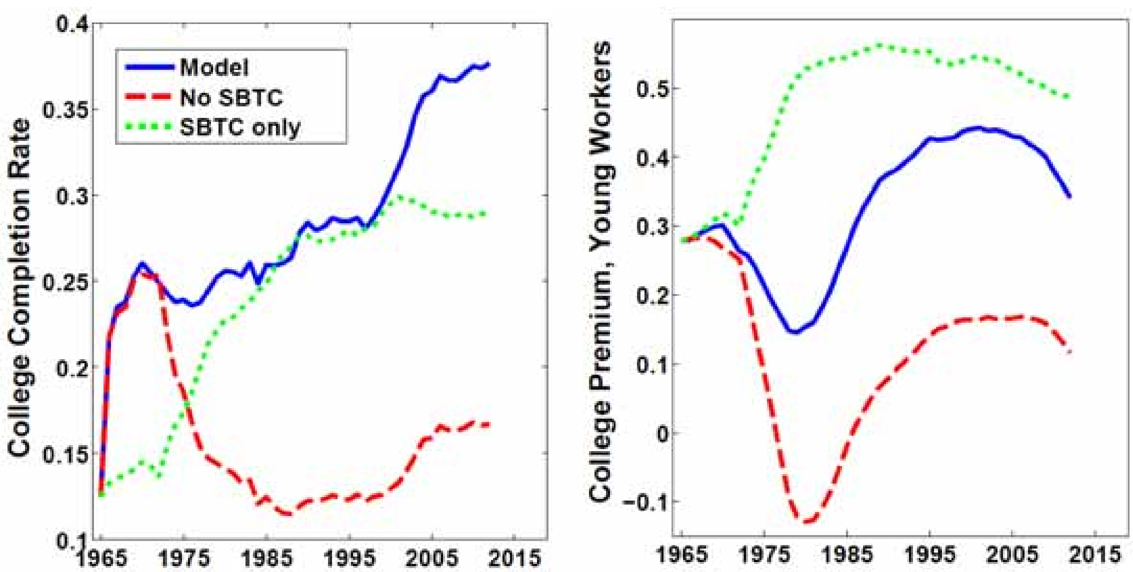
5.1 Counterfactual Experiments

We run three counterfactual experiments to decompose the dynamics of college enrollment and the college premium into exogenous shifts in supply and demand. In the first experiment we allow the technology parameters to change, and solve for equilibrium quantities with the cohort effect and tuition held to the initial BGP levels. The college completion rates and college premia in this experiment are labeled "SBTC only" in Figure 8. In the second experiment the factors that shift supply are allowed to change, and the technology parameters are held constant at the initial BGP values. The results are labeled "No SBTC" in Figure 8.

In the final experiment, we fix schooling to the initial BGP choice function $s(Z)$. This eliminates the supply response to changes in the exogenous variables, and also therefore the compositional effect. We compare wages in the benchmark model and in this counterfactual to measure how much the supply response has affected the return to college.

The line labeled "SBTC only" in Figure 8 shows that without shifts in supply, SBTC would have stimulated a steady increase in college completion from 1965 to 2013, and a transitory increase in the college premium from 1972 to 1982. When we eliminate supply side

Figure 8: Decomposition into Components of Change Due to Exogenous Supply and Demand Factors



factors, 28.6% of workers in the 2013 entering cohort choose the high-skilled sector, versus 36.8% in the benchmark case, and a 37.6% enrollment rate in the data. Since 12.7% of workers go to college in the initial steady state, this suggests that economic incentives can explain about two thirds of the increase in college attendance since 1965.

This decomposition turns out to yield a clear linear relationship between SBTC and college completion. A regression of the recovered SBTC series on the change in college completion reveals that each percentage point of SBTC has increased the college educated fraction of the workforce by about .11 percentage points. The regression coefficient is significantly positive. A comparison of ability levels in both sectors reveals that SBTC is responsible for a 5.23% drop in the mean relative ability of skilled workers from 1968 to 1977. Since the mean relative ability of skilled workers fell 25.5% over this period, SBTC can explain about 20.5% of this decline.

Since SBTC alone increases the college premium over the 1970s, the model attributes the decline in the college premium over the 1970s to a large exogenous increase in the cumulative social and institutional forces that promote college attendance. The second experiment ("No SBTC") shows that without SBTC, supply side forces produce a small increase in higher education, from 12.5% in 1965 to 16.6% in 2013. Since the cohort effect and real tuition rise at roughly the same rate, the shift in supply is relatively small. Rising relative supply contributes a 7.2% decrease in relative wages from 1968 to 1977, and an 8% decrease from 1965 to 2013. This is reflected in the decline in the college premium in this experiment.

Cumulative changes in equilibrium relative wages in the final counterfactual with fixed schooling are displayed in Table 4. Relative wages follow the same pattern as SBTC in Figure 6: rapid SBTC in the 1970s produces a 36.14% increase in relative wages, and the increase in relative wages slows down with the post-1975 deceleration in SBTC. By comparing the two columns of Table 4 we see the effect of changes in relative supply on the return to college. Absent both supply shifts and a supply response to SBTC, the relative wage of highly educated workers would be 77.1% larger in 2013.

6 Conclusions

We have provided a heterogeneous-agent overlapping generations model designed to explain trends both in educational attainment and the earnings differential between people with and without higher education. Our model attributes the decline in the college premium in the 1970s to erosion in the relative quality of young college educated workers since lower skilled people optimally chose to enter college. We believe that this is an important channel for explaining the behavior of the college premium.

Several extensions would enhance our quantitative results and provide evidence to validate or refute the model. A key feature of our model is that agents are heterogeneous in two dimensions, physical strength and mental ability. In our analysis, workers without a college education supply physical strength, and workers with a college education supply mental ability. Future research could examine the robustness of this assumption using occupational data, constructing a measure the physical and mental intensity of each occupation. We identify SBTC by calibrating the model to match college enrollment, it would be interesting to compare our results with those from an alternative model in which college education is not necessary for supplying mental labor. Our quantitative results also rest on the assumption of a fixed distribution of innate skill. It would be productive to relax this assumption, perhaps in a Ben-Porath type model with endogenous investment in human capital at college or on the job. Finally, to understand changes in the college premium for older workers, one might build imperfect substitution between younger and older workers into the model.

By enriching our understanding of how workers sort themselves across different activities, further research may ultimately serve to improve our society’s exploitation of its key natural resource, human capital.

A Data Appendix

All nominal data are converted to real using the implicit price deflator for personal consumption expenditures (NIPA Table 2.3.4). Like in the NIPA, real quantities are measured in constant 2005 US Dollars.

Income and Educational Attainment

The data are taken from the 1962–2014 March Current Population Surveys, made available by the Minnesota Population Center (see Flood et al. (2015)). We process the data following Autor, Katz, and Kearney (2008). We include full time, full year (FTFY) wage and salary workers. Full year workers are those who work at least 40 weeks per year. Full time workers work thirty-five hours per week or more, and are explicitly identified in data. We exclude unpaid family members, all self-employed workers before 1976, and self-employed workers in non-incorporated businesses in 1976 and all later years.

Annual income for FTFY workers is the sum of four income variables: wages and salary from the longest job held over the year, other wage income, business income, and farm income. Following Katz and Murphy (1992), topcoded values are replaced with 1.5 times the topcode. Weekly income is the quotient of annual income and estimated weeks worked. Before 1976, weeks worked over the previous year are intervalled: individuals report weeks worked within intervals of 1-13 weeks, 14-26 weeks, 27-29, etc. From 1976 on, individuals report any integer number of weeks between 0 and 52. For years before 1976, the intervalled values are replaced with median weeks worked among individuals who report working any number of weeks within the given interval in 1976.

Full time earnings are weighted by the product of the sampling weight and weeks worked. Individuals with full-time weekly earnings below \$67 per week in 1982 dollars are dropped from the data[9]. Nominal data are made real using the implicit price deflator for personal consumption expenditures (NIPA Table 2.3.4).

For sectoral assignment, before 1992 the CPS includes each worker's completed years of education. We categorize workers who had finished four years of college as high skilled (type h), and all others as low-skilled (type l) workers. Starting in 1992, the CPS reports the highest degree attained, so type h workers are those with at least a bachelor's degree.

Data from the 1965 CPS (covering earnings year 1964) are used for calibration. There are 11 observations in the 1965 data of FTFY wage and salary college workers younger than 23 (so younger than 22 in the earnings year). These, along with 37 observations with negative probability weights, are dropped. After this processing we have 16,469 observations on earnings and schooling of FTFY workers.

Population

The size of the entering cohort n_t from 1964 to 2013 is the size of the 18-year old population in July in the quarterly intercensal population estimates. For 2014 to 2060, we set n_t equal to

[9] \$67 is half of the weekly earnings for a full-time worker at the 1982 minimum wage of \$3.35 per hour.

projected 18-year old population in the middle series of the 2012 National Population Projections. The data can be found at census.gov.

Survival Probabilities

Survival probabilities are based on the projected age-specific death rates that the U.S. Census Bureau uses to produce its population projections. We calculate survival probabilities for each year when new projections are released using data in the appropriate Census publication, and interpolate for years in between. New projections are published on average once every four years.

From 2012 to 2060, survival probabilities are the mortality rates used in calculating the 2012 projections, and are available at `census.gov` (Select People, then Population Projections, then National Population Projections, then Downloadable Files, and download the middle series of Table 3.). We assume that mortality is unchanged after 2060. Mortality rates in 2000 and 2008 are were also found at `census.gov`. We follow the Census Bureau in assuming that survival probabilities were unchanged between 2000 and 2004.

Before 1990, quadrennial projections are published in the Census Bureau’s P-25 population projection reports. (Mortality rates were not included in the P-25 reports released in the 1990s.) Survival rates in 1986, 1982, and 1976 were published respectively in Appendix Table B4-A of U.S. Bureau of the Census (1989), in Appendix Table B4-A of U.S. Bureau of the Census (1984), and in Appendix Table B-3 of U.S. Bureau of the Census (1976). Before 1976, the P-25s report five-year survival rates for five-year age groups. We assume the five year survival rates give the fraction of people aged at the midpoint of the five year age group who survive to the midpoint of the next age group. We interpolate across time to estimate one year survival rates for each cohort, then interpolate across cohorts on the first year to estimate one-year survival probabilities on the first year of the data, which is normally two years prior to the publication of the P-25. This is done for all the P-25s published between 1965 and 1976.

Test Scores

Wirtz et al. (1977) reports mean math and verbal SAT scores from 1952 to 1977. Mean scores after 1972 for college-bound seniors are available in the College Entrance Examination Board’s *Total Group Profile Report*, College Board (2014). In 1995, scores were re-centered to enforce a mean of 500 on both the math and verbal sections of the test. We estimate the re-centered pre-1972 using the overlapping data between 1972 and 1977. We inflate the pre-1972 data using the percentage difference between the scores on the two reports.

Real Tuition

Nominal tuition data come from Digests of Education Statistics published by the National Center for Education Statistics, part of the U.S. Department of Education. We use the data from column 15 in Table 330.10, “Average undergraduate tuition and fees and room and board rates charged for full-time students in degree-granting institutions, 1963-63 through 2012-13” of the 2013 Digest. This is average tuition and required fees for 4-year public institutions. We use public school tuition as the best available measure of the true cost of a college credential because public tuition is lower. The data are made real using the NIPA price deflator for personal consumption expenditures. While the 2013 Digest had not been published as of February, 2015, data tables from the 2013 Digest were available online at `nces.ed.gov`.

B Derivation of the Likelihood Function

The data cover all full-time, full year workers in the March CPS surveys conducted in the 1960s. Let Y_k, i_k, s_k, and ω_k denote the log earnings, age, schooling, and CPS probability weight for the k^{th} person in the sample. s_k indicates whether person k had finished four years of college. The likelihood of observation k is the joint density of (Y_k, s_k), conditional on age, and denoted $f(Y, s \mid i)$.

Suppose first that $i \geq 4$. Let $b_{s,i}(Y) = Y - \log(w_s) - h_{s,i}$ for $s \in \{h, l\}$. For any particular agent, let s' denote the sector in which that agent does not work. So for example if $s = l$, then $s' = h$. Then,

$$\Pr[y < Y \,\&\, s \mid i] = \Pr\left[Z_s \leq b_{s,i}(Y),\ \ Z_{s'} < c_s(Z_s), Z_s > d_s\right] \tag{10}$$

d_l and d_h are defined in Section 3.2.

$$\Pr[y < Y \,\&\, s \mid i] = \int_{d_s}^{b_{s,i}(Y)} \int_{-\infty}^{c_s(Z_s)} \phi_2(Z; \nu) dZ_{s'} dZ_s \tag{11}$$

If $i < 4$ and $s = l$, then equation 11 is divided by $\Pr[s = l]$. Differentiate 11 with respect to Y to find the conditional joint density. For $i \geq 4$, and with $b_{s,i} = b_{s,i}(Y)$ for legibility,

$$f(Y, s \mid i) = \frac{1}{\sigma_s} \phi\left(\frac{b_{s,i} - \mu_s}{\sigma_s}\right) \Phi\left[\frac{1}{\sqrt{1-\rho^2}}\left(\frac{c_s\left(b_{s,i}\right) - \mu_{s'}}{\sigma_{s'}} - \rho\left(\frac{b_{s,i} - \mu_s}{\sigma_s}\right)\right)\right]$$

The likelihood function with sample size N is

$$L(\nu,\beta) = \sum_{k=1}^{N} \omega_k \, log\, f(Y_k, s_k \mid i_k)$$

C Computational Appendix

To find equilibrium wages, it is sufficient to solve for $\widehat{w}_{l,t}$ and set $\widehat{w}_{h,t}$ using equation 12 below:

$$\widehat{w}_{h,t} = \hat{\alpha}_{h,t}\left[1-\left(\frac{\hat{\alpha}_{l,t}}{\widehat{w}_{l,t}}\right)^{\frac{\psi}{1-\psi}}\right]^{\psi} \tag{12}$$

To show this, divide $\widehat{w}_{h,t}$ and $\widehat{w}_{l,t}$ as defined in equation 2, and substitute in the zero profits condition $\widehat{w}_{h,t}\, N_{h,t} + \widehat{w}_{l,t} N_{l,t} = \hat{Y}_t$. Rearrange to find that for $s \in \{l, h\}$,

$$N_{s,t} = \left(\frac{\hat{\alpha}_{s,t}^{\psi}}{\widehat{w}_{s,t}}\right)^{\frac{1}{1-\psi}} \hat{Y}_t$$

and so zero profits implies that equation 12 holds.

We find the market clearing wages along the balanced growth path by narrowing a band around the equilibrium value of $\widehat{w}_l$ until convergence, with $\widehat{w}_h$ set using equation 12. We select a trial value of $\widehat{w}_l$, and calculate the supplies using equation 6. This trial value becomes the lower or upper bound of the band depending on whether there's an excess demand or supply for unskilled labor. The new trial value is the midpoint of the band.

Along the transition path, we solve for equilibrium wages at each period t as follows. We first guess a trial sequence of expected future wages, and calculate expected future aggregate supplies. We then update the trial expected unskilled wage sequence $E_t[\widehat{w}_{l,t+i}]$ for $i \geq 0$ using the expected marginal products, and the trial expected skilled wage sequence using equation 12. This is repeated for each period until the difference between the marginal products and trial wages is within a pre-specified error tolerance. In period *t,* actual wages $\widehat{w}_{h,t}$ and $\widehat{w}_{l,t}$ equal the time *t* expected values.

References

Abraham, K., and J. Spletzer (2009), New Evidence on the Return to Job Skills, *The American Economic Review: Papers and Proceedings* 99, 52-57.

Acemoglu, D., (1998), Why do New Technologies Complement Skills? Directed Technical Change and Wage Inequality, *The Quarterly Journal of Economics* 113, 300-323.

Acemoglu, D., and D. Autor (2012), What Does Human Capital Do? A Review of Goldin and Katz's ‘The Race Between Education and Technology’, *NBER Working Paper 17820.*

Autor, D., L. Katz, and M. Kearney (2008), Trends in U.S. Wage Inequality: Re-Assessing the Revisionists, *The Review of Economics and Statistics* 90, 300-323.

Ben-Porath, Y., (1967), The Production of Human Capital and the Life Cycle of Earnings, *Journal of Political Economy* 75, 352-365.

Borjas, G. J. (1987), Self Selection and the Earnings of Immigrants, *The American Economic Review* 77, 531-553.

Card, D., and T. Lemieux (2001a), Can Falling Supply Explain the Rising Return to College for Younger Men? A Cohort-Based Analysis, *The Quarterly Journal of Economics* 116, 705-746.

Card, D., and T. Lemieux (2001b), Going to College to Avoid the Draft: The Unintended Legacy of the Vietnam War, *The American Economic Review* 91, 97-102.

Castro, R., and D. Coen-Pirani (2014), Explaining the Evolution of Educational Attainment in the U.S., Working Paper.

College Board (2014), 2014 College-Bound Seniors: Total Group Profile Report. College Entrance Examination Board, New York, NY.

Flood, S., M. King, S. Ruggles, and J. R. Warren (2015), *Integrated Public Use Microdata Series, Current Population Survey: Version 4.0*. [Machine-readable database]. Minneapolis: University of Minnesota.

Greenwood, J., and M. Yorukoglu (1997), 1974, *Carnegie-Rochester Conference Series on Public Policy* 46, 49-95.

Guvenen, F., and B. Kuruscu (2010), A Quantitative Understanding of the Evolution of the U.S. Wage Distribution, 1970-2000. *NBER Macroeconomics Annual 2009*, 24.

Guvenen, F., and B. Kuruscu (2012), Understanding the Evolution of the U.S. Wage Distribution, *Journal of the European Economic Association* 10, 482-517.

Ingram, B., and G. Neuman (2006), The Returns to Skill, *Labor Economics*, 13, 35-59.

Juhn, C., D. I. Kim, and F. Vella (2005), The Expansion of College Education in the United States: is there Evidence of Declining Cohort Quality?, *Economic Inquiry* 43, 303-315.

Juhn, C., K. Murphy, and B. Pierce (1993), Wage Inequality and the Rise in Returns to Skill, *Journal of Political Economy* 101, 410-442.

Heathcote, J., K. Storesletten, and G. Violante (2008). The Macroeconomic Implications of Rising Wage Inequality in the United States, *NBER Working Paper 14052*.

Katz, L., and K. Murphy (1992), Changes in Relative Wages 1965-1987: Supply and Demand Factors, *The Quarterly Journal of Economics* 107, 35-78.

Krussell, P., L. Ohanian, J. V. Rio-Rull, and G. Violante (2000), Capital-Skill Complementarity and Inequality: A Macroeconomic Analysis, *Econometrica* 68, 1029-1053.

Lemieux, T. (2006), The Mincer Equation Thirty Years After Schooling, Experience, and Earnings. In S. Grossbard-Shechtman (Ed.), *Jacob Mincer, A Pioneer in Modern Labor Economics*, New York: Springer.

Magalhaes, M., and C. Hellstrom (2013), Technology Diffusion and its Effects of Social Inequalities, *Journal of Macroeconomics* 37, 229-313.

Mincer, J. (1974), *Schooling, Experience, and Earnings*, New York: Columbia University Press.

Murphy, K., and F. Welch (1990), Empirical Age-Earnings Profiles, *Journal of Labor Economics* 8, 202-229.

Roy, A. (1951), Some Thoughts on the Distribution of Earnings, *Oxford Economic Papers* 3, 135-146.

Taubman, P., and T. Wales (1972), Mental Ability and Higher Educational Attainment in the Twentieth Century, *NBER and the Carnegie Commission on Higher Education*.

U.S. Bureau of the Census (1976) Projections of the Population of the United States: 1977 to 2050, Current Population Reports, Series P-25, No. 601. U.S. Government Printing Office, Washington D.C.

U.S. Bureau of the Census (1984) Projection of the Population of the United States, by Age, Sex, and Race: 1983 to 2080, Current Population Reports, Series P-25, No. 952, U.S. Government Printing Office, Washington D.C.

U.S. Bureau of the Census (1989) Projection of the Population of the United States, by Age, Sex, and Race: 1988 to 2080, Current Population Reports, Series P-25, No. 1018, U.S. Government Printing Office, Washington D.C.

Wirtz, W. et al. (1977), *On Further Examination: Report of the Advisory Panel on the Scholastic Aptitude Test Score Decline*, College Entrance Examination Board.