Public Policy, Technological Change, and the Evolution of Educational Attainment

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Abstract

The goal of this paper is to develop and calibrate a quantitative general equilibrium model to account for the joint evolution of educational attainment and relative wages among education groups in the U.S. over the 20th century. The key exogenous explanatory variables we consider are skill-biased technical change, U.S. education policies, and demographic changes. The main features of the model are: heterogeneity in ability among individuals; three levels of sequential educational attainment: less than high school, high school, and college; public and private colleges, frictionless asset market; endogenous schooling costs and skill prices; skill-biased technical change.

Keywords: Public and Private Education, Tuition Policy, Skill-biased Technical Change.

JEL Classification: I2, J2, O1.

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1 Introduction

The goal of this paper is to develop and calibrate a quantitative model to account for the joint evolution of educational attainment and relative wages among education groups in the U.S. over the 20th century. The key exogenous explanatory variables we consider are skill-biased technical change, U.S. education policies, and demographic changes. We are not only interested in matching initial and final attainment levels, but also in explaining the different medium-run variations that are observed in the data from one decade to the next.\footnote{Restuccia and Vanderbroucke (2008) construct a simple model to evaluate the specific role of educational premiums for the rise in postwar attainment. In addition to considering additional factors driving attainment, our approach differs from theirs in that we focus on the evolution of attainment over the whole 20th century (not just attainment today relative to attainment right after WWII).} In the literature so far, there has been no attempt at addressing this question in a comprehensive and systematic way.

The history of educational attainment during the 20th century can be roughly split into two parts (Goldin and Katz, 2008). The period before WWII was characterized by rapidly increasing rates of high school attendance and graduation (the high school movement). In this period, wage differentials among skill groups have tended to decline as documented by Goldin and Katz (2008) using the Iowa Census and other sources. Between 1950 and 1970, college graduation rates exhibited rapid growth accompanied by upward-trending college premia. Starting in 1970 measures of growth in educational attainment at both high school and college level show a significant slowdown. College enrollment rates fall in the 1970s, and then start rising again the 1980s but at a slower pace than in the 1950s and 1960s. High school graduation rates stagnate or even decline after 1970. The college-high school premium has notably declined during the 1970s, increased dramatically in the 1980s, and experienced a significant slowdown starting in the late-1990s (Autor, Katz and Keraney, 2008). The post-WWII period is also characterized by faster growth in educational attainment (and labor force participation) by females than by males. While we abstract from this important development in the current version of the paper, we plan to extend the benchmark model to account for differences among genders in future versions. We review the evidence on educational attainment in detail in Section 3.

This evidence, if taken at face value, presents a serious challenge to the view that returns to education alone have been the driving force behind the increase in attainment over the last century. The empirical literature suggests that other factors might have played an important role. Goldin and Katz (2008) emphasize the role played by the diffusion of public secondary education during the first half of the 20th century in accounting for the rise in high school graduation rates. Similarly, the analysis in Card and Lemieux (2001), Fortin (2006), and
Bound and Turner (2007) points to the importance of school resources in explaining the slowdown in educational attainment after 1970. They point to the fact that large baby-boom cohorts of new students entered college beginning in the late 1960s, and extending into the early 1980s. This increase was not matched either by an increase in public spending on education, or by an increase in college tuition. College revenues have been rising only since the early 1980s.

Our starting point is a simple benchmark model, sharing some features with Heckman, Lochner and Taber (1998) and Restuccia and Vanderbroucke (2008). The setup is an overlapping generations model with time-varying cohort size. Within each cohort, individuals differ in ability at the time when they begin attending school. This initial human capital can be either used to produce goods and earn income or to accumulate more human capital. We abstract from frictions in financial markets so that individuals make education choices to maximize the present discounted value of lifetime earnings net of direct schooling costs. At the beginning of their lives, individuals are enrolled in high school and decide whether to drop out or complete this degree, and whether to continue their education and obtain a college degree. Human capital accumulation occurs only at school, in a sequential fashion, and depends on learning ability and on teachers’ human capital. We endogenize schooling costs by postulating that all teachers are college graduates hired competitively on the labor market. While high schools are assumed to be entirely publicly funded, college education can be either public or private. In the public system, expenditures per student are constrained by the amount of public funding for higher education and college tuition is subsidized out of general tax revenue. Students attending private colleges, instead, can optimally choose the quality of their education but receive no subsidy. Finally, we embed this schooling choice problem in a general equilibrium setting by using an aggregate production function to endogenize skill-specific wages.

To make this model quantitative, we plan to solve it by assuming an initial steady state in 1900 circa and then simulating a transition to a new steady state far into the future. We will then iteratively search for the set of parameters that provide a satisfactory fit to the joint evolution of educational attainment and relative wages over the course of the 20th century. The main data source for this exercise is the U.S. Census for individual data on educational attainment and earnings and publicly available data on the financing of education (expenditures and tuition) in the U.S. In the current version of the paper we illustrate its main mechanisms by focusing on a steady state, calibrating the model, and performing a series of policy experiments. We consider (i) an increase in tuition subsidies, (ii) an increase in public expenditures on education at both the high-school and college levels, (iii) an increase in public expenditures on education at the college level only, and (iv)
a technology shift favoring college-educated workers. Our current results show a negligible
effect on attainment of tuition subsidies and public expenditures directed at college level.
The latter arises due to fully offsetting general equilibrium effects. When public expenditures
increase in all education levels, we observe an increase in high-school graduation. Finally,
only skill-biased technological change is able to significantly increase college graduation.

2 Literature Review

This paper is related to various literatures that are briefly (and probably incompletely)
reviewed below. To facilitate the review we organize the related literature by broad topics.

Evolution of educational attainment and skill-biased technological change. Katz and Goldin (2008) illustrate in great detail the evolution of educational attainment
and wage inequality in the US over the course of the 20th century. We draw heavily on their
descriptive work in our Section 3. Heckman et al. (1998) were the first ones to incorporate
human capital accumulation (in the form of schooling choices and on-the-job-training) in
a general equilibrium setting to explain the joint evolution of educational attainment and
the skill premium. Differently from them and most of the other papers listed below, we
allow for more levels of schooling, model explicitly education policies, endogenize the cost of
education, focus on the entire 20th century, and distinguish between males and females. He
and Kuruscu (2009) build a model of school attendance and accumulation of human capital
on the job around the distinction between raw labor and human capital. Restuccia and
Vanderbroucke (2009 a and b) focus on the decision problem of school attendance and the
intensive margin of labor supply to explain the evolution of educational attainment and
hours worked. A large literature (see for example Krusell et al. (2000)) studies the evolution
of the skill premium but does not endogenize human capital accumulation. Heathcote et
al (2009) set up a general equilibrium model with endogenous schooling and skill prices to
evaluate the macroeconomic effect of higher wage inequality. They focus on the post 1968
period. Hendricks and Schoelman (2009). Kaboski (2004) is in spirit close to our work in
that he analyzes the role of shifts in the supply of human capital to explain the reduction
in skill premia that occurred in the US in the first half of the 20th century. Specifically, he
draws from Goldin and Katz (2008) description of the high school movement to argue that
the rapid expansion in years of schooling in the first half of the century is consistent with
the decline in returns to schooling. Our model is quite different from Kaboski’s. In addition
to the general features described above, we consider an overlapping generation structure
instead of a static setting.
Effect of education policies. In addition to Kaboski (2004)’s work, Gallipoli, Meghir, Violante (2008) develop a general equilibrium model to analyze the effect of higher education policies (loans and means-tested government grants). They consider a long-run equilibrium and therefore do not focus on changes in educational attainment and policies over time. Bound and Turner (2007) argue that higher education subsidies are important for educational attainment. They exploit variations in cohort size across US states and over time to show how a 10 percent rise in the size of college-age population results in a 4 percent percent decline in college completion rates within states. They interpret these findings as evidence that individuals in large cohorts might be crowded out of of college if state-level education funding does not adjust to the change in cohort size.

Female labor force participation. A large literature has studied the causes and consequences of the rise in women labor force participation. In a closely related paper Jones et al. (2003) set up a model to quantify the importance of demand and supply-side factors to the evolution of female labor supply. Like our paper, they consider an exogenous component of the gender wage gap, modelled as a tax on female wages and an endogenous component of gender wage gap related to the endogenous accumulation of human capital.

3 Empirical Evidence

3.1 Evolution of Educational Attainment and Education Policies

The history of educational attainment in the U.S. cannot be understood without reference to the evolution of institutions of public education (see Goldin and Katz, 2008 for a more detailed description).

Broad trends. The following table (coming soon) presents data for each decade of a decomposition of current expenditures per student in the two levels of schooling we consider in this paper: elementary and secondary (ES from now on) and post-secondary (PS). For each schooling level we can write:

\[
\frac{E}{S} = \frac{E}{Y} \times \frac{Y}{P} \times \frac{P}{S},
\]

where \(E\) denotes aggregate current (i.e. education-related) expenditures, \(S\) denotes total enrollment, \(Y\) is a measure of real income (such as real GDP), \(P\) denotes the population of age corresponding to a given level of schooling (5–17 for ES and 18–21 for PS). Using equation (1) we can decompose the decade-by decade growth in spending per student in its three components illustrated above.
High school movement. The so-called “high school movement” - the dramatic increase in high school enrollment and graduation rates and the diffusion and standardization of high school education - represents the major development in the first 40 years of the 20th century: “The public high school was recreated in the early 1900s to be a quintessentially American institution: open, forgiving, gender neutral, practical but academic, universal, and often egalitarian... The reinvention of the high school brought secondary education to the youth who would otherwise have gone to work.” (Goldin and Katz, 2008, pages 231-232). Before the high school movement, the goal of secondary education was mainly to prepare students for college and the emphasis was mainly on academic subjects. The “modern” high school also taught non-academic courses such as vocational courses (woodworking), commercial ones (bookkeeping), “life” courses (music). It also expanded the set of academic courses (foreign languages, sciences with labs) taught. The push toward more applied disciplines came mostly from the bottom up: households requested schools to offer courses that were relevant to the new occupations into which youths were headed. As Goldin and Katz (2008, page 245) explain the new public high school supplanted private secondary institutions which would mostly shut down when a new high school would open. Enrollment in private primary and secondary schools was about 8 percent in 1900 and 11 percent at the end of the 20th century. Goldin and Katz also emphasize (page 198) that the spread of public high schools was not due to a policy of the federal government, but rather the result of the initiative of local school districts. The states subsidized poorer school districts and determined that school districts without a high school would have to pay tuition on behalf of the their students attending high school in other districts.

From an economic perspective, the key question concerns the rationale for the new public high school. Could a similar expansion of secondary education as the one observed during the period 1900–1940 have been brought about with private, instead of public, schools? The answer to this question is important because it might be argued that public education spending simply crowded out private education spending without affecting the overall resources allocated to secondary education. Goldin and Katz (2008, page 208) argue that the public nature of the institution was indeed important because of imperfections in the capital market that either prevented households with school-age children from financing their education through external loans or prevented children in need of being educated from borrowing within the family from their parents. This imperfection would justify a public intervention in the provision of education. We do not explicitly address this important issue in this paper. However, by ruling out a private alternative in primary and secondary education we are implicitly assuming that the observed expansion in years of schooling could not have occurred without public expenditure in this area. At the other extreme, one might relabel public
spending on primary and secondary education in our model as “private” spending, instead (although equal for each child). According to this interpretation, our approach emphasizes the fact that educational investments involve not only the opportunity cost of one’s time, as assumed by most of the literature, but also real resources.

**College education.** Figure 1 (coming soon) shows the evolution of the share of enrollment in public institutions of higher education. Enrollment in public institutions of higher education displays two periods of rapid expansion, from 1900 to 1930 and from the early 1950s to the mid 1970s. This expansion brought public enrollment from 22 percent in 1900 to 77 percent in 2000. In our setting we abstract from borrowing constraints and assume that taxes are lump-sum (and as such they do not influence the decision to attend college). Thus, the effect of public subsidies for higher education is to induce less-able individuals to attend college relative to a fully private system. In addition, in our model, the public demand for higher education tends to lower private spending by increasing the relative price of the education good. Public policy had an impact on college enrollments through the 1944 GI Bill that affected WWII, Korean, and Vietnam veterans and more directly through the draft deferment policy at the time of the Vietnam war (Card and Lemieux, 2001).

### 3.2 Trends in Years of Schooling and Degrees

**Broad trends.** Figure 2 (coming soon) presents average years of schooling by age 40 for U.S. born men and women by birth cohort for cohorts born between 1900 and 1978. People born in 1900 had an average of about 8.7 years of schooling by age 40. Average years of schooling increased steadily from one generation to the next until the generation born in 1951. Across 51 generations, years of schooling increased on average by about 1 year per decade. Subsequent generations experienced relatively little gains in average years of schooling. The generation born in 1978 had only 0.2 years of schooling more than the 1951 generation, or about 13.8 years of schooling.

Figure 3 (coming soon) presents high school and college graduation rates by birth cohort. From the perspective of degrees, the gains in years of schooling for cohorts up to the 1951 one were driven first by an increase in high school and then in college graduation rates. Specifically, among individuals born in 1900, the high school graduation rate was about 25 percent. For individuals born 50 years later, the graduation rate reached almost 90 percent. Then, at the beginning of the 1970s, the high school graduation rate suddenly stopped and even declined, showing a modest recovery for the most recent cohorts. College attainment reveals similar dynamics. For the 1900 cohort, the college graduation rate was about 5

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2The high school (college) graduation rate is the fraction of people in a given birth cohort that has obtained a high school (college degree) by the age of 30.
percent. For the 1951 cohort, about 27 percent of individuals aged 30 and over graduated from college. During the 1970s, college graduation declined for both sexes, resuming only, and especially for women, with the 1960 cohort.

Men vs. women. Average years of education for women in the 1900 birth cohort slightly exceeded men’s, 8.9 against 8.5. Men’s average years of schooling reached women’s levels with the 1920 cohort. For subsequent cohorts up to the 1955 one, men’s years of schooling exceeded women’s. For subsequent cohorts women’s average years exceeded men’s with a gap of about 0.4 years in the 1978 cohort. In terms of degrees, in the 1900 cohort the higher average years of schooling by women were associated with a higher graduation rate from high school (slightly under 30 percent for women against slightly above 20 percent for men) and a lower graduation rate from college (slightly above 5 percent for men and slightly below 5 percent for women). For the 1951 cohort, about 30 percent of men aged 30 and over graduated from college and about 25 percent of women did. During the 1970s, college graduation declined for both sexes, but especially for men. In fact, the growth in graduation resumed quickly for women, while it remained stagnant for men. For the 1978 cohort, about 35 percent of women graduate from college, while only about 27 percent of men do.

4 Model

We consider an overlapping generations model of schooling and education choice. Individuals differ in terms of innate ability and birth cohort. Financial markets are complete, so education choices are not constrained by individual financial resources. Education is public at the primary and secondary level and either private or public at the tertiary one. The model is a general equilibrium one, in which government expenditures are financed through lump-sum taxes and skill prices are determined by the usual marginal product conditions. Differently from most of the literature we assume that human capital accumulated at the tertiary level is an input in the production of new human capital. This feature of the model allows us to endogenize the cost of providing education. The inputs in the production of human capital at each schooling level are teachers’ human capital, innate ability, and own human capital accumulated in the previous schooling level. Workers are different in terms of gender and ability to learn.

4.1 Setting

Lifetime. An individual’s economic life starts at age six and goes until age $L_\tau$, where $\tau$ denotes a cohort. We abstract from retirement. Individuals select the number of years
of schooling $s$, where $0 \leq s \leq S_2$. While we focus on years of schooling, for the purpose of comparing the model with the data it is convenient to mark the years of schooling that correspond to the attainment of a high school degree ($S_1$), and college degree ($S_2$).

**Heterogeneity.** Agents in the model are heterogeneous in four dimensions: ability to learn, denoted by $\theta$, cohort of birth, denoted by $\tau = -\infty, \ldots, +\infty$, age, denoted by $l = 0, \ldots, L_\tau - 1$, and gender, denoted by $g = m, f$. We use the indices $g$ and $\tau$ to distinguish between gender and cohort of birth. We assume that the ability distribution is the same across all cohorts and we denote it by $G(\theta)$.

**Raw Labor and Human Capital.** Each individual is endowed with $k^g$ units of raw labor and accumulates human capital by attending school or working. Before any schooling or work experience, initial human capital is simply $h_{0\tau}$. The human capital accumulation equation for an agent who attends $1 \leq s \leq S_2$ years of school is:

$$h_{s\tau l} = \begin{cases} g(\theta, h_{s\tau l-1}, x_{\tau l}) & \text{for } 1 \leq l \leq s \\ z(\theta, h_{s\tau l-1}) & \text{for } l > s \end{cases}, \quad (2)$$

where $x_{\tau l}$ represents the quantity of education input in school year $l$, and previously accumulated human capital is $h_{s\tau l-1}$. The output of the education process is newly produced human capital $h_{s\tau l}$. Note that we are assuming that raw labor does not affect the accumulation of human capital, and that an individual attending school cannot work.

**Preferences and Budget Constraint.** Individuals maximize the present value of their lifetime utility, discounted at the rate $\beta$. Utility depends whether an agent works or not. Men are assumed to always work so their lifetime utility is:

$$\sum_{l=0}^{L_\tau-1} \beta^l u(c_{\tau+l}), \quad (3)$$

where $c_{\tau+l}$ denotes the consumption of an agent of cohort $\tau$ in year $l$ of his life. Women might work in the market or work at home. If they work in the market, their utility function takes the form (3). If they work at home it is:

$$\sum_{l=0}^{L_\tau-1} \beta^l u(c_{\tau+l} + \nu_\tau), \quad (4)$$

where $\nu_\tau$ is a constant that captures the value of home production. The specification in (4)

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3We interpret $\theta$ in a broad sense (see Heckman and Carneiro, 2002) to reflect both an individual’s innate ability as well as the influence that family background would have on his/her ability to learn.
corresponds to a setting in which raw labor (only) is used to produce home goods and the home good is a perfect substitute for the market good.

We assume that financial markets are complete and there are no borrowing constraints (Cameron and Heckman, 2001), so there is one lifetime budget constraint, which takes the following form for an individual that attends school for \( s \) years and participates in the workforce:

\[
\sum_{l=0}^{L_{\tau}-1} R^l c_{\tau+l} + P_{\tau,s} + \sum_{l=0}^{L_{\tau}-1} R^l T_{\tau+l} = \sum_{l=s}^{L_{\tau}-1} R^l w^g_{srt+l},
\]  

where \( R \equiv (1 + r)^{-1} \) and \( r \) is the exogenous interest rate, \( P_s \) denotes the present value of direct schooling costs for school level \( s \), \( T_{\tau+l} \) represents lump-sum taxes in year \( \tau + l \), and \( w_{srt+l} \) the earnings in period \( l \) of life for an individual born in cohort \( g \) who attends school for \( s \) years. Lump-sum taxes might depend not only on an individual’s age and cohort, but also on his/her gender and ability. Earnings are defined as:

\[
w^g_{srt+l} \equiv (1 - \phi^g_{\tau}) \left(k^g w^k_{\tau+l} + h_{srt+l} w^h_{\tau+l}\right),
\]

where \( w^k_{\tau+l} \) and \( w^h_{\tau+l} \) are the unit prices for raw labor and human capital respectively. The parameter \( \tau^g_{\tau} \) represents the effect of women discrimination in the labor market. It is zero for men: \( \phi^m_{\tau} = 0 \) and strictly positive for women. The tax on women is rebated to the economy at large. If a woman does not participate in the workforce instead the present value budget constraint is:

\[
\sum_{l=0}^{L_{\tau}-1} R^l c_{\tau+l} + \sum_{l=0}^{L_{\tau}-1} R^l T_{\tau+l} = 0.
\]

This reflects the fact that in this case the woman chooses not to get any education.

**Government.** The government collects lump-sum taxes and spends them on education and possibly other items. The lump-sum nature of taxes guarantees that they can always adjust to balance the government’s budget without affecting schooling decisions. Thus, we can consider variation in the government’s education policy without taking into account the feedback effect on taxes. Government policy is summarized in the quadruple \( \left(T_t, x_{t}^{hs}, x_{t}^{pb}, \delta_{t}^{pb}\right) \).

We define \( x_{t}^{hs} \) to be the average (per student) amount of school output per student enrolled in high school in year \( t \) and assume that all students enrolled in high school in the same year receive the same amount. Similarly, \( x_{t}^{pb} \) denotes the average amount of school output guaranteed by a public college in year \( t \). Last, the government subsidizes public college expenditures at the rate \( \delta_{t}^{pb} \), with students paying the remaining portion.

**Production of goods.** Goods are produced using raw labor and human capital as
inputs:
\[ Y_t = F_t \left( K_t - K_{t}^{\text{ed}}, H_t - H_{t}^{\text{ed}} \right), \]

where \( F_t \) is a constant returns to scale production function. The inputs \( H_t \) and \( K_t \) denote the stocks of human capital and raw labor available in calendar period \( t \). The fact that \( F \) is indexed by \( t \) reflects the possibility of technological shifts. Since teachers’ input requires both raw labor and human capital, we subtract the raw labor \( K_{t}^{\text{ed}} \) and human capital \( H_{t}^{\text{ed}} \) employed in the education sector from the production inputs. The index \( t \) denotes time. The sector that produces goods behaves competitively hiring raw labor and human capital:

\[
F_{tK} \left( K_t - K_{t}^{\text{ed}}, H_t - H_{t}^{\text{ed}} \right) = w_t^k, \quad (6) \\
F_{tH} \left( K_t - K_{t}^{\text{ed}}, H_t - H_{t}^{\text{ed}} \right) = w^h, \quad (7)
\]

Education. Schools operate a constant returns to scale technology that takes as input human capital and raw labor and generates as output education. The latter affects the production of new human capital as in (2). The representative school production function is:

\[ X_t = H_t \left( K_{t}^{\text{ed}}, H_{t}^{\text{ed}} \right). \]

The problem of schools is to maximize profits:

\[
\max_{K_{t}^{\text{ed}}, H_{t}^{\text{ed}}} \left\{ p_t X_t - w_t^k K_{t}^{\text{ed}} - w^h H_{t}^{\text{ed}} \right\},
\]

where \( p_t \) denotes the price of one unit of school output. Schools are competitive so optimality requires that \( p_t \) equals the marginal cost of production. The marginal conditions are:

\[
p_t H_{tK} \left( K_{t}^{\text{ed}}, H_{t}^{\text{ed}} \right) = w_t^k, \quad (8) \\
p_t H_{tH} \left( K_{t}^{\text{ed}}, H_{t}^{\text{ed}} \right) = w^h. \quad (9)
\]

We distinguish between public and private education. Public education is such that the government guarantees a certain (fixed) quantity of the good \( X \). This quantity is denoted by \( x_{t}^{\text{hs}} \) for school grades up to the end of high school and \( x_{t}^{\text{pb}} \) for college. There is no private option until college and there is no direct cost of attending public school up to the end of high school. Public tertiary education is subsidized at the rate \( \delta_t^{\text{pb}} \). Tertiary education might be public or private, instead. In private education the agent can choose the level of \( X \) to purchase. Private tertiary education is subsidized at the rate \( \delta_t^{\text{pr}} \). Equilibrium in the market
for education requires that at each point in time the total demand and supply of education
are equal to one another:

\[ x_t^{hs} \psi_t^{hs} + x_t^{pb} \psi_t^{pb} + x_t^{pr} \psi_t^{pr} = X_t, \quad (10) \]

where \( \psi_t^{hs} \) and \( \psi_t^{pb} \) denote public primary-secondary and tertiary school attendance in \( t \), and \( \psi_t^{pr} \) denotes private tertiary attendance. Average units of education demanded by students attending private college in year \( t \) are denoted by \( \overline{x_t^{pr}} \).

**4.2 Consumption, Schooling, and Participation Choices**

Individuals maximize utility subject to the budget constraint. For given choice of education and labor force participation individuals solve for the optimal consumption profile. The first order condition for consumption of an agent who participates in the workforce is:

\[ u'(c_{t+l}) = \beta R^{-1} u'(c_{t+l+1}) \text{ for } l = 0, ..., L - 2. \quad (11) \]

For an agent who does not participate it is:

\[ u'(c_{t+l} + \nu_t) = \beta R^{-1} u'(c_{t+l+1} + \nu_t). \]

In what follows we assume that:

\[ \beta R^{-1} = 1 \]

so that agents choose a constant consumption profile:

\[ c_{t+l} = c_t \]

for all values of \( l \). Given that \( \nu_t \) is also constant over somebody’s lifetime (although not across cohorts), the problem of the agent is to choose the schooling and work option that maximizes the present value of income net of direct schooling costs and including \( \nu_t \), if the worker chooses not to participate.

**Define** the present value of gross earnings associated with \( s \) years of schooling:

\[ W_{s\tau g} = (1 - \phi_{s\tau}) \sum_{l=s}^{L-1} R^l u^g_{s\tau l}. \]

The different options are:
• Not participate in the workforce and not get educated:
  \[ V_{\tau}^{nl} (\theta) = \sum_{l=0}^{L-1} R^l v_\tau. \]

• Participate in the workforce and not get educated:
  \[ V_{\tau g}^{ns} (\theta) = W_{0g}. \]

• Attend primary-secondary school for weakly less than \( S_1 \) years:
  \[ V_{\tau g}^{hs} (\theta) = \max_{s \in [1, S_1]} W_{s\tau g} (\theta). \]

• Complete secondary education and attend public college for \( s \in [S_1 + 1, S_2] \) years:
  \[ V_{\tau g}^{pb} (\theta) = \max_{s \in [S_1+1, S_2]} \left\{ W_{s\tau g} (\theta) - P_{st}^{pb} \right\}, \]
  \[ P_{st}^{pb} \equiv \left( 1 - \delta_{\tau+l}^{pb} \right) \sum_{l=S_1}^{s-1} R^l p_{r+l} x_{r+l}^{pb}. \]

• Complete secondary education and attend private college for \( s \in [S_1 + 1, S_2] \) years:
  \[ V_{\tau g}^{pr} (\theta) = \max_{s \in [S_1+1, S_2]} \left( \max_{x_{\tau+l}^{pr}} \left\{ W_{s\tau g} (\theta) - P_{st}^{pr} \right\} \right), \]
  \[ P_{st}^{pr} \equiv \left( 1 - \delta_{\tau+l}^{pr} \right) \sum_{l=S_1}^{s-1} R^l p_{r+l} x_{r+l}^{pr}. \]

An agent \((\theta, \tau, g)\) selects the option that gives the highest net income, \( V_{\tau g}^j (\theta) \). For convenience we partition the set of types \((\theta, \tau, g)\) based on their choices. Let \( \Theta^j_{\tau g} \) for \( j = nl, ns, hs, pb, pr \) denote the set of \((\theta, \tau, g)\) such that option \((j, s)\) is optimal. Note that the direct schooling costs in the budget constraint (5) are \( P_s = 0 \) if \( s \leq S_1 \).

The aggregate stocks of human capital and raw labor \( H_t \) and \( K_t \) are determined by the optimal choices of described above.

### 4.3 Equilibrium

We are now ready to define an equilibrium for this economy. Given the exogenous sequences of population by cohorts \( \{N_t\} \), government policies \( \{T_t, x_t^{hs}, x_t^{pb}, \delta_t^{pb}\} \), technologies
\( \{F_t, H_t\} \), the interest rate \( r \), a competitive equilibrium is represented by a sequence of raw labor and human capital rental prices \( \{w^k_t, w^h_t\} \), price per unit of education \( \{p_t\} \), consumption choices \( \{c_t(\theta)\} \), labor force participation and education choices, spending choice for private college \( \{x^{pr}_t(\theta)\} \), aggregate and sectoral stocks of human capital and raw labor \( \{K_t, H_t, K^\text{ed}_t, H^\text{ed}_t\} \), such that:

- labor force participation choices are optimal;
- education choices and associated expenditures are optimal;
- consumption choices satisfy the Euler equation (11) and budget constraint (5);
- rental prices are equal to the marginal products of human capital and raw labor, as in (8)-(9) and (6)-(7);
- the aggregate human capital and raw labor stocks are consistent with the agents’ participation and education choices;
- the market for education clears, i.e., equation (10) holds.
- the government budget is balanced.

5 Calibration

5.1 Functional forms

- Human capital accumulation equation:

\[
g(\theta, h, x) = \theta h^\gamma x^\alpha.
\]

- Experience:

\[
z(\theta, h) = C\theta^k h.
\]

- Production function for output:

\[
F = (K - K^\text{ed})^\eta (H - H^\text{ed})^{1-\eta}.
\]

- Production function for education sector:

\[
H = B (K^\text{ed})^\lambda (H^\text{ed})^{1-\lambda}.
\]
• Ability distribution:

\[ G(\theta) \text{ lognormal with parameters } (\mu, \sigma^2). \]

### 5.2 Parameter values

We choose to set a-priori some of the model’s parameters and use a matching routine to set the others.

Parameters set a-priori:

- Worklife duration and time to graduation:

\[ L = 55, \ S_1 = 12, \ S_2 = 16. \]

- Interest rate and discount factor:

\[ \beta = R^{-1} = 0.96. \]

- Accumulation of experience (abstract from experience for now):

\[ C = 1, \xi = 0. \]

- Endowment of raw labor for males (normalization):

\[ k^m = 1. \]

Calibrated parameters (15 parameters):

- Technology:

\[ \alpha, \gamma, \eta, B, \lambda. \]

- Ability distribution:

\[ \mu, \sigma^2. \]

- Human capital and raw labor:

\[ k^f, h_0. \]

- Females:

\[ k^f, \nu, \phi. \]
5.3 Calibration Targets

The economy is assumed to be in a steady state in the year 1900. This year is used to calibrate the model’s parameters. The following 30 moments were used for the calibration:

- Histogram of educational attainment for men and women (16 moments). These are the data, obtained from the 1940 Census (this is the first Census year for which data on years of education is available). The data refers to individuals who were at least 63 in 1940 (or 23 in 1900):4

<table>
<thead>
<tr>
<th>Years of education</th>
<th>Males</th>
<th>Females</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>8.4</td>
<td>7.4</td>
</tr>
<tr>
<td>1–4</td>
<td>17.3</td>
<td>14.0</td>
</tr>
<tr>
<td>5–7</td>
<td>22.4</td>
<td>21.6</td>
</tr>
<tr>
<td>8</td>
<td>33.1</td>
<td>34.3</td>
</tr>
<tr>
<td>9–11</td>
<td>6.3</td>
<td>8.4</td>
</tr>
<tr>
<td>12</td>
<td>5.9</td>
<td>8.9</td>
</tr>
<tr>
<td>13–15</td>
<td>3.1</td>
<td>3.4</td>
</tr>
<tr>
<td>16 and over</td>
<td>3.6</td>
<td>2.0</td>
</tr>
</tbody>
</table>

- Enrollment rate of males in higher education. This is 64% according to 120 Years of American Education (1993, Table 24).

- Enrollment in public institutions of higher education. This is 22% according to Goldin and Katz (1998, Table 3).

- Labor force participation rate of women 16–60. This is 20% according to the 1900 Census.

- Government education spending as a share of GDP. This is about 1% according to the Tax Foundation (2000). We adjust for the lack of capital in the model by scaling this number up by $1/0.7$.

---

4The table is based on the IPUMS variable EDUC, which denotes highest grade completed.
• Ratio of spending per student in higher education vs primary and secondary. This is 8.2 according to 120 Years of American Education (1993, Table 22, 34).

• Female returns to schooling. According to Goldin and Katz (2000, Table 5), this is 3% for years of schooling before high school; 10% for high school; 15% college for young single females 18-34.

• Returns to schooling for males. According to Goldin and Katz (2000, Table 5) this is 5% up to high school, 12% in high school; and 15% for college for men 18-34.

• Gender wage gap. Goldin (1990, Table 3.2 ) reports a ratio of female to male earnings across all occupations of 0.46.

• Ratio of government spending on higher education to total spending on higher education. This is 48% according to 120 Years of American Education (1993, Table 33).

• Ratio of tuition spending on higher education to total spending on higher education. This is 27% according to 120 Years of American Education (1993, Table 33).

The objective function in the calibration of the model is the sum of squared percent deviations of the moments in the model from the moments in the data.

5.4 Solution Algorithm

A few preliminary steps allow us to simplify the solution of the model in the steady state. Specifically, the algorithm is such that one can express everything as a function of the price ratio \( w^h/w^k \). This is because: 1) the education choice part of the model is homogeneous in \( w^k \); 2) the ratio \( p/w^k \) can be solved as function of \( w^h/w^k \). Manipulating the static first order conditions for choice of inputs by the two sectors we obtain:

\[
\frac{p}{w^k} = \frac{1}{B\eta} \left( \frac{\lambda w^h}{1 - \lambda w^k} \right)^{1-\lambda}. \tag{12}
\]

The algorithm then proceeds as follows:

• Guess \( w^h/w^k \).

• Find \( p/w^k \) from equation (12).

• Solve for the optimal choice of education and obtain the aggregates \( K \) and \( H \).

• Find the allocations in two sectors, \( K^{ed} \) and \( H^{ed} \). From the firms’ first order conditions:
\[ K^{ed} = \frac{w^h}{w^k} \frac{\lambda}{1 - \lambda} H^{ed}, \]
\[ H^{ed} = \frac{\frac{\eta}{1 - \eta} H \left( \frac{w^h}{w^k} \right) - K}{\frac{w^h}{w^k} \left( \frac{\eta}{1 - \eta} - \frac{\lambda}{1 - \lambda} \right)}. \]

- Verify that the market clearing condition for education good is satisfied:
\[ x^{hs} \psi^{hs} + x^{pb} \psi^{pb} + \pi^{pr} \psi^{pr} + \pi^{pr} \psi^{pr} = B \left( K^{ed} \right)^\lambda \left( H^{ed} \right)^{1 - \lambda}. \]

- After the loop for \( w^h/w^k \) has converged one can solve for \( p \):
\[ p = B^{-1} \frac{1 - \eta}{1 - \lambda} \left( \frac{1 - \eta}{\eta} \right)^\eta \left( \frac{\lambda}{1 - \lambda} \right)^\lambda \left( \frac{w^h}{w^k} \right)^{\eta - \lambda}, \]
and for \( w^k \) from equation (12).

### 6 Parameters and Fit

The following table presents the calibrated parameters of the model:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>( \delta_g )</th>
<th>( \delta_p )</th>
<th>( \eta )</th>
<th>( \lambda )</th>
<th>( \mu )</th>
<th>( \sigma )</th>
<th>( \alpha )</th>
<th>( B )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.92</td>
<td>0.16</td>
<td>0.55</td>
<td>0.00</td>
<td>1.46</td>
<td>0.42</td>
<td>0.058</td>
<td>5.89</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>( \gamma )</th>
<th>( x^{pb} )</th>
<th>( x^{hs} )</th>
<th>( \phi )</th>
<th>( \nu )</th>
<th>( k^f )</th>
<th>( h_0 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.65</td>
<td>138.1</td>
<td>23.9</td>
<td>0.69</td>
<td>0.66</td>
<td>0.20</td>
<td>0.49</td>
<td></td>
</tr>
</tbody>
</table>

The following tables present the comparison between the moments predicted by the model and the moments in the data.

### 7 A Century Later...

We revisit the moments used to calibrate the model for the year 2000.

- Histogram of educational attainment for men and women (16 moments). These are the data, obtained from the 2000 Census (note that the categories are slightly different
because the variable EDUC in the 2000 Census puts together 7 and 8th grade):

<table>
<thead>
<tr>
<th>Educational attainment (% of group)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Years of education</strong></td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>1–4</td>
</tr>
<tr>
<td>5–6</td>
</tr>
<tr>
<td>7–8</td>
</tr>
<tr>
<td>9–11</td>
</tr>
<tr>
<td>12</td>
</tr>
<tr>
<td>13–15</td>
</tr>
<tr>
<td>16 and over</td>
</tr>
</tbody>
</table>

- Enrollment rate of males in higher education. This is 43.7% according to “Gender Differences in Participation and Completion of Undergraduate Education and How They Have Changed Over Time” (2005).
- Enrollment in public institutions of higher education. This is 77% according to the Digest of Education Statistics (2000).
- Labor force participation rate of women 16–60. This is 70% according to the 2000 Census.
- Government education spending as a share of GDP. This is about 5.84% according to the Digest of Education Statistics (2009). We adjust for the lack of capital in the model by scaling this number up by 5.84/0.7.
- Ratio of spending per student in higher education vs primary and secondary. This is 2.7 according to “Education Indicators: an International Perspective” (2003).
- Female returns to schooling. According to the 2000 Census, this is 13.7% for years of schooling before high school; 12.4% for high school; 13.4% college for young (not necessarily single) females ages 18-34.\(^5\)
- Returns to schooling for males. According to the 2000 Census this is 10.5% up to high school, 9.9% in high school; and 11.2% for college for men ages 18-34.\(^6\)

\(^5\)Regressions control for race dummies and potential experience. Notice that returns to schooling are higher for females than for males. This is consistent with the review of the literature by Goldin (1990, page 88).
\(^6\)Regressions control for race dummies and potential experience.
• Ratio of government spending on higher education to total spending on higher education. This is 65% according to the Digest of Education Statistics (2009). NEED TO PERFORM SAME ADJUSTMENTS TO DATA AS IN 1900.

• Ratio of tuition spending on higher education to total spending on higher education. This is 28% according to the Digest of Education Statistics (2009). This is basically the same as in 1900.

8 Comparing Steady States

TBA

9 Conclusions

TBA