Explaining the Evolution of Educational Attainment in the U.S.*

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Abstract

Can the educational attainment of the 1932-1972 cohorts be explained by the evolution of skill prices, tuition, and education expenditures? A model of investment in human capital with heterogeneous learning ability is calibrated to match the educational attainment of the 1932 and 1972 cohorts. According to the model, college attainment should have grown relatively slowly for the 1932-1948 cohorts and relatively quickly for the 1960-1972 cohorts. The data shows the opposite pattern. When extended to allow for cross-cohort variation in average learning ability, calibrated to match the evolution of high school dropout rates, the model explains the attainment data well.

Keywords: Educational Attainment, Human Capital, Skill Prices, Inequality, Cohorts.

JEL Classification: I24, J24, J31, O11.

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1 Introduction

In this paper we study the evolution of educational attainment of a large number of cohorts of U.S. males. We consider the 1932–1972 birth cohorts and document how male college attainment rose sharply for the early cohorts peaking with the 1948 one.[1] It then declined for about ten cohorts, followed by an increase at a relatively slow pace till the 1972 one. We ask whether a quantitative model of investment in schooling and human capital can explain these and other features of the data. The driving forces of educational attainment across cohorts are the dynamics of skill prices, tuition, and education expenditures. The benchmark model cannot explain the evolution of educational attainment. Its failure can be attributed to a discrepancy between the timing of the rise in skill prices for college (mostly the 1980's and 1990's) and the timing of the rise in college attainment (mostly the 1950's and 1960's). We then consider an extension in which the distribution of ability by birth cohort is allowed to vary over time and calibrate this process to match the evolution of high school dropout rates by cohort. This version of the model is remarkably successful in accounting for the evolution of college attainment.

Understanding the evolution of educational attainment is clearly important because of the tight link between investment in education, individual welfare, and wage inequality.[2] In this paper we follow a standard theory of human capital accumulation and take seriously the view that skill prices are an important - perhaps *the* most important - quantitative factor in explaining the evolution of educational attainment over time. While some authors favoring this view, (e.g. Restuccia and Vandenbroucke (2010)), focus on the *long-run* evolution of educational attainment, others have argued that the *inter-cohort* variation can also be explained by the dynamics of skill prices.[3] A number of other authors have, instead, expressed concern about the lack of a stronger reaction of college attainment to the rise in the college premium in the 1980's, suggesting that additional forces, in addition to skill prices, should

[1]In this paper we focus on white males. For papers studying the educational attainment of women, jointly with their labor supply decision, see Jones, Manuelli, and McGrattan (2003) and Rendall (2010), among others.

[2]There is also an extensive and well-known literature following the seminal work of Katz and Murphy (1992) and including Topel (1997) and Goldin and Katz (2008), arguing that shifts in attainment are a major causal source of variation in returns. Our analysis is consistent with this view, but we focus on the causality working in the opposite direction.

[3]For example, Topel writes that: "When increased demand raises the return to skills, basic economics tells us that investment in skills will rise, just as more houses will be built when the demand for them rises." Heckman, Lochner, and Taber (1998, page 46) argue that skill prices alone can account for the dramatic rise in college enrollment in the 1960s. Unfortunately they do not report the measures of attainment predicted by their model.

be taken into account.[4]

Our reading of this literature is that it is an open question whether the inter-cohort evolution of educational attainment can be accounted for by the dynamics of skill prices. One of our main contributions is to try to answer this question using a calibrated structural model of education choices. In order to emphasize the evolution of skill prices and other additional forces, such as tuition and schooling expenditures, we purposely keep the model simple in its key elements: individuals are characterized by heterogeneous abilities to learn, financial markets are frictionless, and upon graduation an individual's human capital evolves over time through the exogenous accumulation of experience. To implement the model quantitatively, we first use U.S. Current Population Survey and Census data combined with the structure of the model to measure directly the growth rate of skill prices by education group and over time. We then use these growth rates together with the decision problem of a selected number of cohorts to calibrate the model's parameters. Finally, we ask whether the calibrated model can explain the evolution of attainment for the cohorts that are not used in the calibration exercise. Conditional on the measured dynamics of skill prices, the calibrated model predicts that college attainment should have grown relatively slowly for the 1932–1948 cohorts and relatively quickly for the 1960–1972 cohorts. This pattern is inconsistent with the data. Between 1950 and 1970, college graduation rates exhibited rapid growth accompanied by mild growth in college premia, while between 1980 and 2000 college graduation rates grew at a slower pace with rapid growth in college premia (see Autor, Katz, and Kearney, 2008, for a summary of the evidence on college premia).

We draw two conclusions from our analysis. First, the reasons for the slowdown in college attainment in the last forty years are likely to have the same fundamental cause that led to a stagnation in high school graduation rates since the late 1960s. This conclusion is somewhat independent of the model and is supported by the observation that the slowdown in college and high school graduation rates occurred for the same cohorts. Second, our quantitative analysis based on the calibrated model is consistent with the interpretation that the slowdown in educational attainment is due to a decline in the productivity of schooling investment at all levels of schooling.

This paper is related to a growing literature, encompassing macro and micro studies, on the determinants of schooling over time for the U.S., and across countries. Focusing on the post-World War II period, Restuccia and Vandenbroucke (2010) investigate the role of the increase in the returns to schooling in accounting for the increase in educational attainment via an explicit model of schooling. A fundamental difference from our analysis is that they

[4] See, for example, Goldin and Katz (2008, page 347) and Carneiro and Heckman (2003, page 3), among others.

focus on educational attainment at two points in time, 1950 and 2000, whereas we are mostly interested in how attainment evolved between these two periods. Our analysis is consistent with theirs in that we calibrate the model's parameters in such a way that, jointly taken, skill prices, tuition, and schooling expenditures (in that order of importance) account for the variation in educational attainment experienced between the 1932 and the 1972 cohorts.[5] Goldin and Katz (2008) study the history of educational attainment and education earnings premia during the entire 20th century. According to their analysis, the pre-WWII period was characterized by a rapid expansion of high school and college graduation rates accompanied by declines in high school and college wage premia. We do not consider this period mainly for lack of comprehensive wage data.[6]

A number of papers have tried to explain the inter-cohort evolution of college attainment in the U.S. Some use reduced-form empirical models, while others adopt structural approaches. Among the former, Topel (1997, 2005) emphasizes the high correlation between the variation in college attainment and contemporaneous returns to college since the early 1960's to argue that returns drive attainment. Our work, instead, highlights an important discrepancy in the magnitudes: in the data, college attainment grew the fastest when contemporaneous returns grew the slowest, and vice-versa. Our main conclusion is more in line with Card and Lemieux (2001a) who conclude their econometric analysis of Current Population Survey (CPS) data by acknowledging that (comparing the 1930-50 cohorts with the 1950-70 ones) "even after accounting for the effect of changes in returns to education and cohort size, the dramatic trend shift in the inter-cohort rate of growth of college graduation for men...is essentially unexplained." Relative to Card and Lemieux (2001a), we offer a systematic, quantitative analysis encompassing the whole postwar period and employing a structural model of schooling choices. The latter allows us to deal explicitly with the issue of selection across schooling levels and the related problem of measuring skill prices separately from average wages (Heckman, Lochner, and Taber, 1998, and Hendricks and Schoellman, 2009).

In the structural literature, Keller (2013) argues that the pattern of fast rise and sudden slowdown in college attainment we focus on can be explained by the decline in the growth rate of average earnings in the U.S. that occurred in the 1970's. As pointed out by Bils and Chang (2000) the growth rate of earnings is a determinant of educational attainment. Our

[5] Restuccia and Vandenbroucke (2013) is another related paper, focusing on the decision problem of school attendance and the intensive margin of labor supply to explain the joint evolution of educational attainment and hours worked.

[6] Goldin and Katz (2008) use the Iowa Census and other sources. Kaboski (2004) formalizes some of their arguments to reconcile the rapid expansion in years of schooling in the first half of the century with the decline in returns to schooling observed during this period.

benchmark model includes this effect but it cannot explain the attainment data. Donovan and Herrington (2013) model the evolution of college enrollment over time in a model with borrowing constraints and heterogeneity in initial assets. They attribute the initial fast rise in educational attainment for the 1930-50 cohorts to "changes in college costs". Donovan and Herrington (2013) explain the slowdown in educational attainment for the post-1950 cohorts by resorting to a version of myopic expectations by which agents predict the relevant college premium using a moving average of college premia in the previous 25 years. We also find that a version of our model with myopia improves the fit of the attainment data relative to perfect foresight, but this is not sufficient to provide a satisfactory account of the evidence. A unique feature of our work relative to Keller (2013) and Donovan and Herrington (2013)'s papers is that, in addition to encompassing the driving forces they consider, we seek to explain the evolution of high school, in addition to college, graduation. This is an important distinction because we find that the same forces that are responsible for the stagnation in high school graduation rates for the post 1948 cohorts can also account for the slow rise in college completion. Thus, important information is potentially lost by exclusively focusing on the college level. Like us, Gemici and Wiswall (2011) consider multiple levels of educational attainment, including high school graduation and focus on the evolution of college major choices by cohort and gender. However, their model has implications for the stagnation in male college attainment between the 1940 and 1960 cohorts. They attribute it to the counteracting effects of movements in skill prices, working to increase attainment by the 1960 cohort relative to the 1940 one, and higher college tuition, working in the direction of decreasing it (see their Table 5, panel B). Both of these factors are also present in our model, but tuition plays a quantitatively smaller role in our case.[7]

Finally, the paper is also related to work on the variation in educational attainment across countries and over time in the labor and development literatures.[8]

The rest of the paper is organized as follows. Section 2 presents the features of the data we focus on. Section 3 introduces the model and characterizes its qualitative properties. Section 4 describes the empirical implementation of the model. Section 5 presents and discusses the results from the benchmark model. Section **??** presents our suggested resolution to the puzzle. Section 7 concludes. The appendices contain proofs of propositions and provide additional information about the data used in this paper and aspects of the calibration

[7] According to Gemici and Wiswall (2011)'s model (see Table 5), the observed increase in tuition between the 1940 and 1960 cohorts contributed to reduce men's college attainment by 21 percentage points.

[8] The former includes papers by Bound and Turner (2002) and Stanley (2003) on the effects of the G.I. bill and Card and Lemieux (2001a), Fortin (2006), Bound and Turner (2007), and Lee (2005) on the effect of cohort size on college attainment. The latter includes papers by Erosa, Koreshkova, and Restuccia (2010), Manuelli and Seshadri (2007), Córdoba and Ripoll (2011), (see Hsieh and Klenow, 2010, for a recent review), (Banerjee and Duflo, 2005), and (Psacharopoulos and Patrinos, 2004), among others.

procedure.

2 Empirical Evidence

In this section we present the stylized facts about the evolution of educational attainment and education earnings premia for different education levels in the U.S. population of white males, ages 23–65.[9]

2.1 Educational Attainment

Our data source for educational attainment are the March CPS, 1964–2010. We allow for five possible educational categories based on the highest completed grade of school or year of college: 1. eight grade or less ("middle school degree"); 2. more than ninth and less than twelfth grade ("high school dropout"); 3. twelfth grade and/or a high school degree or GED ("high school graduate"); 4. one to three years of college but no four-year college degree ("some college"); 5. at least a four-year college degree ("college graduate").[10]

We organize the attainment data in terms of birth cohorts. Figure 1 presents data on educational attainment for the 1928–1986 cohorts.[11] The attainment measures are computed as of age 23, the latest age at which individuals in our model are assumed to begin their working lives. In practice, of course, some individuals take longer to graduate, while others choose to return to school following initial job spells. Moreover, this behavior is likely to change across cohorts. In order to address these concerns, in Figure 1 we report comparable educational attainment numbers for each cohort.[12]

The data shows a rapid increase in achievement for the 1928–1948 birth cohorts. The proportions of individuals with four-year college degrees and some college rises for these cohorts, while the fraction with only a high school degree is constant or declines, and the

[9] See Appendix C.2 for a description of the samples.

[10] The category "some college" includes graduates from two-year college programs. We make a distinction between this and the four-year college category because of important differences in the dynamics of attainment and skill prices between each of them.

[11] In our modelling analysis of Section 3, we restrict attention to the cohorts born between 1932 and 1972. This choice is dictated by the availability of wage data. We would like to focus on the post-WWII period. The earliest representative wage data after WWII were collected in the 1950 U.S. Census and refer to the calendar year 1949. Assuming that an individual drops out of high school at age 16 and begins working at age 17 (as our model assumes), and taking into account that the earliest wage data refer to 1949, this person must be part of the 1932 cohort. We stop with the 1972 cohort to be able to have 15 years of wage data for this cohort starting in 1995 (the year when this cohort's college graduates are assumed to start working).

[12] Our procedure also allows us to infer educational attainment at age 23 for those earlier cohorts for which the CPS does not provide direct information, and thus extend our sample as far back as possible. Appendix C.2.1 contains the details of our procedure.

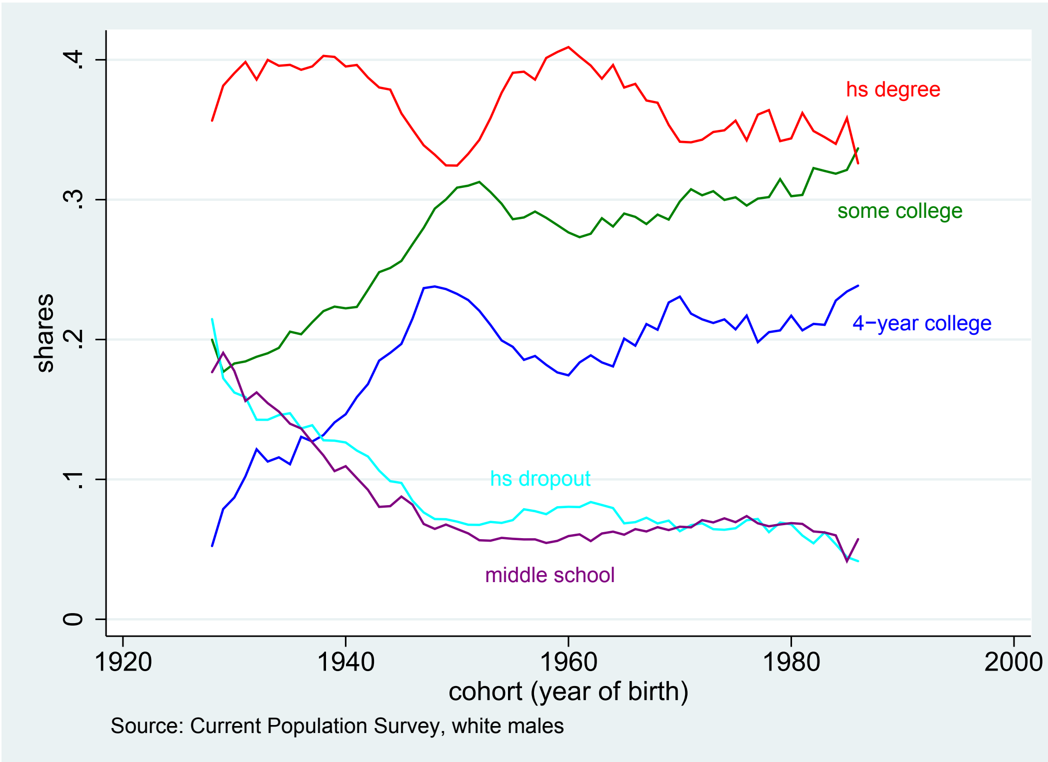


Figure 1: Educational attainment at age 23 by birth cohort.

proportion of high school dropouts and individuals with middle school degrees falls.[13] For the 1949–1960 cohorts, educational attainment in terms of four-year college and some college drops, and the proportion of individuals with only a high school degree rises again. For the post-1960 cohorts the two college-related measures of attainment show mild improvements. These patterns are consistent with the analysis of many other authors, such as Topel (1997, Figure 3), Card and Lemieux (2001a, Figure 9.4), Carneiro and Heckman (2003, Figures 1-3), Topel (2005, Figure 2), Goldin and Katz (2008, Figures 7.1, 7.2 and 9.2), and others.[14]

[13]In Section C.1 of the Appendix we discuss and quantify the evidence on the impact of the Korean and Vietnam wars on the evolution of college attainment. Based on our reading of the literature we conclude that these events had a relatively minor impact on the patterns of attainment discussed in this section.

[14]See also the figures in Acemoglu and Robinson's blog *Why Nations Fail* posted on April 23, 2012 (http://whynationsfail.com/). The evolution of attainment depicted in Figure 1 presents some features which are specific to males. Namely: (i) the proportion of females with a only high-school diploma has been steadily declining, and (ii) female college graduation rates have also experienced a slowdown for the 1949–1960 cohorts, but much smaller in magnitude, and followed by a very strong recovery - college graduation rates are now higher for females. See also Goldin and Katz (2008). While the contrast between male and female attainment is important, in this paper we concentrate our attention on males.

2.2 Education Earnings Premia

Figure 2 shows the evolution of education earnings premia over time (not cohort) using earnings data from the CPS and the 1950 and 1960 Censuses.

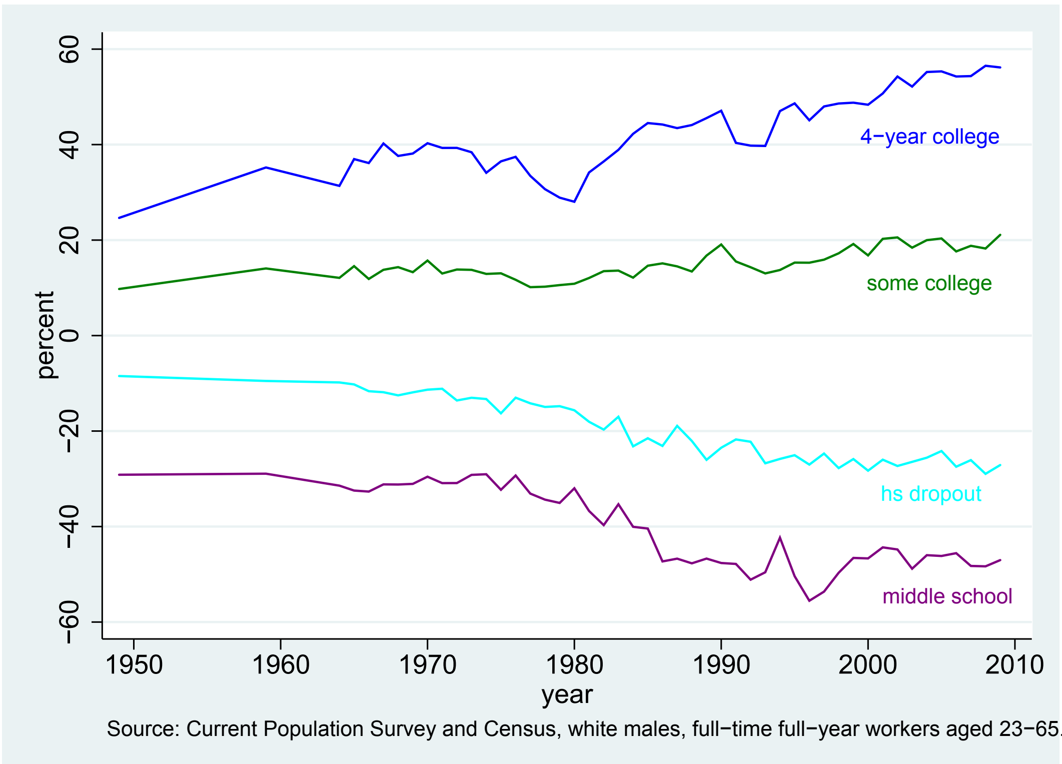


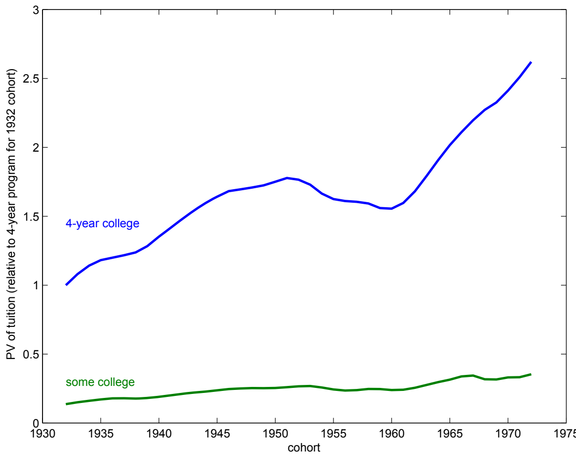
Figure 2: Education wage premia relative to high school degree.

We define education earnings premia as the coefficients in year-by-year cross-sectional regressions of individual-level log weekly earnings on a full set of dummies for potential experience and dummies for education groups. The education earnings premia are defined relative to the group with a high school degree. The relative wage of an individual with a four-year college degree increased slowly during the 1950's until the late 1960's, after which it declined during the 1970's until the year 1980. Since then this relative wage has been increasing steadily. These basic trends are well-known and have been documented elsewhere. See, for example, Autor, Katz, and Kearney (2008, Figure 2 and Table 1). While, differently from some authors (e.g. Restuccia and Vandenbroucke, 2010) we do not equate average wages with skill prices, the skill prices we compute (see Figure 4 below) display similar qualitative trends as the education earnings premia of Figure 2.

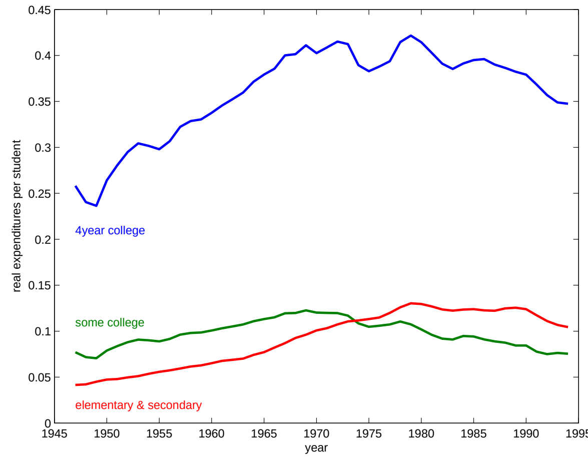
In what follows we first introduce and then calibrate a simple model of schooling choice to answer the following question: can the dynamics of returns to schooling over time explain the cohort-by-cohort evolution of educational attainment?

2.3 Tuition and Education Expenditures

Figure 3a displays the evolution of the average real present value of four- and two-year college tuition faced by an individual in each cohort at the time of entering college.[15]



(a) Tuition



(b) Real expenditures per student

Figure 3: Tuition and education expenditures in the data

As Figure 3a shows, tuition in four-year college programs has increased at a faster pace for the cohorts born after 1960 (see for example Kane (1999)). This trend might have contributed to the relatively slow rise in four-year college attainment for these cohorts. For this reason we include variation in tuition over time in our model economy.

Figure 3b displays the postwar evolution of real expenditures per student in elementary and secondary schools, and two and four-year college programs.[16] The most notable feature for our purposes is that real per student expenditures rise at the post-secondary schooling levels until 1970, and then either suddenly stagnate or decline. Some authors have also highlighted some of the changing patterns of per student expenditures, including Kane, Orszag, and Apostolov (2005), Bound and Turner (2007), Fortin (2006).[17] You (2011) attempts to measure the contribution of the secular raise in education quality to U.S. economic growth

[15]The interest rate used to discount tuition is five percent per year, as consistent with the calibration of the model. The tuition data comes from the Digest of Educational Statistics. See Appendix C.3 for the details.

[16]Nominal expenditures per student are obtained from the Digests of Education Statistics, and deflated using the NIPA's Personal Consumption Expenditure price index for education services. See Appendix C.4 for details.

[17]The sudden shift in per pupil expenditures is striking. Kane, Orszag, and Apostolov (2005) suggest that a reason for it was a change in state budget priorities, with health spending receiving a higher weight.

using a model similar to ours. Given that the standard Ben-Porath (1967) model of investment in human capital emphasizes both time and goods as inputs in the creation of new human capital, we include both in our model.

3 Model

In order to emphasize the key ingredients necessary to account for the evolution of educational attainment, we purposely focus on a simple model in which individuals differ in terms of birth cohort and learning ability, as well as their taste for education. The model is in partial equilibrium, as we study schooling decisions given the exogenous evolution of skill prices, tuition fees, and schooling quality. Financial markets are frictionless, so education choices are not constrained by an individual's financial resources. Finally, we study the population of individuals with at least a middle-school degree.[18]

3.1 Basic Elements of the Model

We study the education choices of individuals in different cohorts τ. Calendar time is denoted by t and an individual's age by l. We assume that schooling choices are made at age 15, and take the convention that $l = 1$ denotes this age.[19] An individual's economic life starts at age $l = 1$ and goes until age $l = L$, at which point the individual dies.[20]

Human Capital Accumulation Human capital is accumulated through schooling and experience. There are four possible education choices, denoted by j. Each schooling level j is characterized by a length of study S_j during which the individual is assumed not to be able to work in the labor market. Specifically, the schooling levels are: four-year college and above ($j = 1$) involving a total of $S_1 = 8$ years of school (in addition to the eight years of middle school); some college ($j = 2$) involving $S_2 = 6$ years of school; high school degree ($j = 3$) for a total of $S_3 = 4$ years of school; and high school dropout ($j = 4$) involving $S_4 = 2$ years of school.

These choices are mutually exclusive. During formal schooling leading up to terminal degree j, human capital for an individual born in year τ with learning ability θ accumulates

[18] The restriction to individuals with at least a middle-school degree is made in order to limit the set of education choices and keep the structure simple. The data in Figure 1 shows a steep decline in the percentage of white men with a middle-school degree or less from the 1928 cohort to the 1948 one. For later cohorts this figure remains constant at around 6 percent.

[19] It follows that calendar time is related to birth cohort and age by the following equation: $t = \tau + 14 + l$.

[20] Notice that we do not include a retirement period in the model. Given the fact that education choices are made at age 15 and that individuals discount the future this assumption is quantitatively innocuous. For the same reason we abstract from changes in the duration of working life across cohorts.

according to the law of motion

$$h_{\tau+15+l} = \theta h_{\tau+14+l}^{\gamma} \left(x_{\tau+14+l}^{j'} \right)^{\varphi} + (1-\mu) \, h_{\tau+14+l} \tag{3.1}$$

where j' denotes the level of schooling in which the agents is currently enrolled. Thus, for example, an agent whose terminal degree is $j = 1$ (four year college) will be enrolled in school level $j' = 4$ at ages $l = 1, 2$, in school level $j' = 3$ at ages $l = 3, 4$, and in school level $j' = 1$ at ages $l = 5 - 8$. Similarly for the other choices. The rest of the notation is as follows: μ is the rate of depreciation and the first-term on the right-hand side of equation (3.1) is the investment at age l for an individual attending school level j'. The latter increases with an individual's ability to learn θ, with the previously accumulated human capital $h_{\tau+14+l}$, and with the quality of education the individual has been exposed to when attending school $x_{\tau+14+l}^{j'}$, when attending school level j'.

The initial human capital, denoted by $h_1 \equiv h_{\tau+14+1}$, is a parameter and is assumed to be the same for all agents in all cohorts. An individual who completes S_j years of schooling obtains human capital $h_{\tau}^{j}(\theta)$, given by the left-hand side of equation (3.1) when $l = S_j$. The ability parameter θ is distributed in the population according to a cumulative distribution function $G(\theta)$.[21] In the benchmark version of the model we maintain the assumption that G is cohort-invariant. We relax this assumption in Section 6.

After the completion of formal education an individual's human capital evolves exogenously over time according to:

$$h_{\tau+14+l}^{j}(\theta) = h_{\tau}^{j}(\theta) \exp\left(\delta_1^j (l - S_j - 1) + \delta_2^j (l - S_j - 1)^2 \right) \text{ for } l = S_j + 1, \ldots, L \tag{3.2}$$

where δ_1^j and δ_2^j are the parameters governing the returns to experience, which are allowed to depend on the schooling level j (but not on calendar year), and $l = S_j + 1$ is the age at which the individual begins his working life.

Preferences Individuals' preferences have two components. The first one reflects consumption over the life-cycle while the second one reflects preferences for specific education choices. Formally, an agent born in year τ with ability θ, and schooling preferences $\boldsymbol{\xi}_i \equiv \left(\xi_i^1, \xi_i^2, \xi_i^3, \xi_i^4 \right)$, maximizes the present discounted value of utility defined as follows:

$$\sum_{l=1}^{L} \beta^{l-1} \ln c_{\tau+14+l}^{j} + \sigma \left(\xi_i^j + \overline{\xi}^j \right), \tag{3.3}$$

[21] We interpret θ in a broad sense (see Carneiro and Heckman, 2002) to reflect both innate ability and the influence that family background would have on it by age 14.

where the parameter β is the constant discount factor. The random variable ξ_i^j represents individual i's preferences for schooling-level j.[22] These shocks are independent across degrees j for the same individual i. We also assume that each ξ_i^j is independently distributed in the population according to a standard type-I extreme value (or Gumbel) distribution. Each individual i is assumed to observe the vector of shocks $\boldsymbol{\xi}_i$ at the beginning of his first period of life ($l = 1$) and before making education and consumption choices.

The parameter $\overline{\xi}^j$ is degree-specific but constant across individuals and over time. It captures the average taste for degree j in the population. Finally, the parameter $\sigma \geq 0$ determines the relative importance of degree-specific preferences relative to the present value of utility from consumption (economic fundamentals) in determining schooling choices. The preference parameters are relevant for quantitative purposes. The idiosyncratic preference shock $\boldsymbol{\xi}_i$ breaks the strict sorting of education choices on learning ability and allows for a degree of ability mixing within each schooling choice. It also ensures that attainment levels are always strictly positive, and respond smoothly to variations in exogenous variables. The average psychic rewards from education $\overline{\xi}^j$ allow us to target the average attainment levels observed in the data. The model's task will be to account for the attainment *dynamics* across cohorts, given the average attainment levels. As σ increases, exogenous preference-related factors become more important in explaining agents' education choices relative to returns to skill. In the limit, as $\sigma \to \infty$, returns to skill become irrelevant.

Expectations In order to make their consumption and schooling decisions at age $l = 1$, individuals in each cohort τ need to formulate expectations about the entire future paths of skill prices, $\{w^j_{\tau+14+l}\}^L_{l=S_j+1}$ for all j. We follow the literature and assume that agents have perfect foresight over the evolution of these prices. In Section 5.3 we consider the alternative hypothesis of myopic expectations and evaluate its importance for the results.

Financial Markets We also assume frictionless financial markets, with no borrowing constraints. We abstract from borrowing constraints not because we do not think they might be important components of the economic environment in which people make education choices. Instead, we are primarily motivated by the desire to start out with the simplest possible model in order to isolate the contribution of skill prices, together the level of tuition itself and education quality, to the evolution of educational attainment across cohorts. As a further motivation, we also notice that primary and secondary schooling in the U.S. are publicly provided, so that the only cost of attending is the opportunity cost of someone's time. Thus, the issue of credit constraints applies only to the college choices $j = 1, 2$.

[22] To save on notation, we omit the subscript i from consumption and human capital choices.

Third, we study the decisions of the cohorts 1932–1972. Cameron and Heckman (2001) have studied the college attendance of the NLSY 1979 cohorts (1957–1964) and found that for these cohorts credit constraints play a minor role in explaining differential rates of college attendance between whites, blacks and hispanics. They emphasize the role played by long-run factors associated with parental background, rather than short-run parental liquidity, in determining college attendance.[23]

Frictionless markets imply that there is one lifetime budget constraint, which takes the following form for an individual of cohort τ and learning ability θ that makes education choice j:[24]

$$\sum_{l=1}^{L} R^{-(l-1)} c^{j}_{\tau+14+l} = \sum_{l=S_j+1}^{L} R^{-(l-1)} (1-\lambda)\, w^{j}_{\tau+14+l} h^{j}_{\tau+14+l}(\theta) - Z^{j}_{\tau}, \tag{3.4}$$

where R is the exogenous gross interest rate, λ is the labor income tax rate, which we assume to be constant, and Z^j_τ is the present value of tuition, as of age $l = 1$, for any individual in cohort τ who picks schooling option j. In what follows we assume that secondary schooling is publicly financed so that tuition is paid only by individuals attending college ($Z^4_\tau = Z^3_\tau = 0$).

3.2 Consumption and Schooling Choices

Individuals maximize utility (3.3) subject to the budget constraint (3.4). They choose a preferred level of schooling and a consumption profile over the life-cycle. Consider the latter problem first. For given choice of education, individuals solve for the optimal consumption profile. The first order condition for consumption is:

$$c^{j}_{\tau+14+l+1} = \beta R c^{j}_{\tau+14+l} \text{ for } l = 1, ..., L-1. \tag{3.5}$$

For simplicity, we assume that the discount factor is such that $\beta R = 1,$ which implies constant consumption over the life-cycle. The planned consumption level of an individual of

[23] However, using the NLSY 1997 (1980-84 cohorts), Belley and Lochner (2007) do document the existence of a positive correlation between parental income and college attendance even after controlling for measures of ability such as the AFQT score. This suggests borrowing constraints may have started to become more important for the most recent cohorts. To the extent that a higher role for borrowing constraints may have coincided with the increase in tuition levels documented in Section 2.3, this feature could further improve the model's ability to explain the decline and relative stagnation in college attainment observed for the post-1955 cohorts.

[24] Notice that individuals cannot insure against the realization of the individual-specific shocks $\boldsymbol{\xi}_i$.

cohort τ and learning ability θ making school choice j is then:

$$c_{\tau}^{j}(\theta)=\frac{\sum_{l=S_{j}+1}^{L}R^{-(l-1)}(1-\lambda)\,w_{\tau+14+l}^{j}h_{l}^{j}(\theta)-Z_{\tau}^{j}}{\sum_{l=1}^{L}R^{-(l-1)}}. \tag{3.6}$$

Replace $c_{\tau}^{j}(\theta)$ into the utility function to obtain an indirect utility function (exclusive of $\boldsymbol{\xi}_i$ and $\overline{\xi}^{j}$):

$$V_{\tau}^{j}(\theta)=\ln\left(c_{\tau}^{j}(\theta)\right)\sum_{l=1}^{L}\beta^{l-1}.$$

An individual i of ability θ and preference vector $\boldsymbol{\xi}_i$ is going to select the education level that solves the following problem:

$$\max_{j}\left\{V_{\tau}^{j}(\theta)+\sigma\left(\xi_{i}^{j}+\overline{\xi}^{j}\right)\right\}.$$

While it is obvious to notice that a higher idiosyncratic preference ξ_i^j for education level j will tilt an agent's decision toward j, the sorting of individuals with different ability levels across education categories is less obvious. The basic result, summarized in Proposition 1, is that for given idiosyncratic preferences, higher ability individuals will tend to sort into higher education levels.

Proposition 1. *If an individual i of cohort τ, with ability θ and preference vector $\boldsymbol{\xi}_i$, is indifferent between education levels j and j', with j' denoting higher attainment ($j' < j$), then an individual i' in the same cohort with higher ability θ', with $\theta' > \theta$ and the same preference vector $\boldsymbol{\xi}_{i'}=\boldsymbol{\xi}_i$, will find it strictly optimal to choose j'.*

Proof. See Appendix A. □

The key to this result is the human capital accumulation equation (3.1). According to the latter, higher ability individuals benefit more from staying in school longer because they experience higher human capital growth.

3.3 Aggregation

Given the individual schooling choices, we are able to compute the main aggregates of interest in our model. The well-known properties of the type-I extreme value distribution imply that the proportion of individuals of type θ in cohort τ who choose schooling level j is:

$$P_{\tau}^{j}(\theta)=\frac{\exp\left(V_{\tau}^{j}(\theta)/\sigma+\overline{\xi}^{j}\right)}{\sum_{i}\exp\left(V_{\tau}^{i}(\theta)/\sigma+\overline{\xi}^{i}\right)}. \tag{3.7}$$

Building on Proposition 1, we can then show that in the aggregate, higher education levels are characterized by individuals of higher ability. Formally:

Proposition 2. *Consider two education levels j' and j, with j' denoting higher attainment ($j' < j$). Then, the relative proportion of individuals choosing education level j' rather than j increases with ability:*

$$\frac{\partial \left[P_\tau^{j'}(\theta) / P_\tau^{j}(\theta) \right]}{\partial \theta} > 0.$$

Moreover, the distribution of ability among agents who choose j' first-order stochastically dominates the distribution of ability among agents who choose j.

Proof. See Appendix B. □

A consequence of Proposition 2 is that earnings premia associated with higher education levels reflect in part sorting by individuals with heterogeneous abilities instead of different skill prices (Taber, 2001).

Our empirical strategy will involve setting parameters so that the model can reproduce some key moments for educational attainment and education earnings premia for a selected number of cohorts. We introduce the following notation and define these moments. First, the proportion of individuals in each cohort τ choosing schooling-level j (i.e. the attainment rate) is denoted by:

$$AR_\tau^j \equiv \int_\theta P_\tau^j(\theta) dG(\theta). \tag{3.8}$$

Second, the education earnings premium between schooling levels j and j' among working members of cohort τ in year t (when they reach age $l = t - \tau - 14$) is defined as follows:

$$EP_{t\tau}^{j,j'} \equiv \frac{w_t^j \overline{h}_{t\tau}^j}{w_t^{j'} \overline{h}_{t\tau}^{j'}}, \tag{3.9}$$

where $\overline{h}_{t\tau}^j$ denotes the average human capital of cohort τ agents in year t conditional on schooling choice j:

$$\overline{h}_{t\tau}^j \equiv \frac{\int_\theta h_{t-\tau-14}^j(\theta) P_\tau^j(\theta) dG(\theta)}{AR_\tau^j}. \tag{3.10}$$

Before turning to the empirical implementation of the model, and in order to develop some intuition for its implications, Proposition 3 summarizes the way attainment rates respond to variations in skill prices.

Proposition 3. *Assume that there is no tuition, or $Z_\tau^j = 0$ for all j. Then, if skill prices of degree j faced by cohort τ were scaled up or down by a factor ψ, with ψ close to 1, the* *degree j's attainment AR_τ^j would change by a factor:*

$$(\psi - 1)\frac{\sum_{l=1}^{L}\beta^{l-1}}{\sigma}\left\{1 - AR_\tau^j\left[1 + \left(CV_\tau^j\right)^2\right]\right\}$$

where CV_τ^j denotes the coefficient of variation of $P_\tau^j(\theta)$ within education level j.

Several comments are in order.[25] First, this expression shows that, as previously indicated, the parameter σ is crucial in determining how attainment responds to economic variables, with lower values implying larger responses. Intuitively, the more important preference shocks are in determining education choices, the smaller the response of attainment is to a given increase in skill prices. Our calibration strategy is to identify σ out of "long-term" attainment responses, in a way the we describe in detail in the next section. Second, the elasticity depends negatively on the current attainment rate. Intuitively, attainment in education level j can be progressively increased through higher skill prices only by enticing agents characterized by more and more adverse taste toward j. Given the distribution of preference shocks, this process runs into natural diminishing returns. Third, the elasticity is lower when there is a relatively high degree of mixing of individuals with different innate abilities into a given education level j. The intuition is similar to the first point, as a high degree of mixing is associated with a high importance of preferences, relative to ability, in determining education choices. Last, while the thought experiment in Proposition 3 pertains to a (permanent) change in relative prices of different degrees, it is important to point out that an increase in the growth rate of all skill prices that keeps the relative prices constant is not neutral in this model. As first pointed out by Bils and Klenow (2000) and further pursued by Keller (2013), changes in the growth rates of all skill prices produce the same effect on attainment as variations in the interest rate.[26] We quantify the importance of this effect in the context of our model in Section 5.2.3.

4 Empirical Implementation

In this section we first describe the calibration procedure and then discuss the predictions of the model for the educational attainment and education premiums of the two cohorts used in the calibration process, i.e., the 1932 and 1972 cohorts.

[25] Notice that the assumption of zero tuition is correct for education levels $j = 3, 4$ while it is only approximate for the college-related choices.

[26] Specifically, a higher growth rate is analogous to a lower interest rate and therefore tends to favor investment in schooling by reducing the opportunity cost of being in school relative to the payoff from the additional schooling.

4.1 Setting the Model's Parameters

The empirical approach we follow in order to set the model's parameters and measure skill prices over time consists of three steps. First, we use the structure of the model and cohort-level data to identify the evolution of skill prices over time, up to their initial level. Second, we set a number of parameters a-priori. Third and last, we calibrate the remaining parameters and the initial level of skill prices in order to match a number of key moments in the data. The following subsections describe each of these three steps.

4.1.1 Step 1 - Evolution of Skill Prices and Experience Profile

The model of Section 3 emphasizes the distinction between earnings, on the one hand, and skill prices on the other. Observed earnings are the product of skill prices and accumulated human capital. The latter is accumulated in school and later in the labor market through experience. In this section we jointly estimate the period-by-period growth rates of skill prices for each schooling choice together with the parameters that determine the returns to experience in equation (3.2).

The essence of our approach is to use variation over time in the average earnings of individuals of a given schooling group and cohort to identify the evolution of skill prices. The challenge in trying to infer skill prices from earnings is the fact that variation in earnings over time might reflect either variation in skill prices or changes in the distribution of ability among individuals who choose a given education level. We solve this identification problem by tracking the evolution of average earnings of members of the *same* cohort and education group over time. The analysis by cohort guarantees that selection into education groups is not changing over time. While this approach allows us to compute the growth rates of skill prices over time, it does not pin down their initial levels (see Section 4.1.3 for a description of how these levels are determined).

Formally, let $w_t^j \overline{h}_{t\tau}^j$ represent the average earnings in period t of workers who belong to cohort τ and make schooling choice j. Average earnings for this group are the product of the skill price w_t^j and the average human capital of those workers $\overline{h}_{t\tau}^j$, where $\overline{h}_{t\tau}^j$ is defined in equation (3.10). Simple manipulation of equation (3.2) shows how the growth rate of average earnings for individuals in cohort τ who choose schooling level j can be decomposed as follows:

$$\ln \frac{w_{t+1}^j \overline{h}_{t+1\tau}^j}{w_t^j \overline{h}_{t\tau}^j} = \ln \frac{w_{t+1}^j}{w_t^j} + \delta_1^j + \delta_2^j \left(2\left(t-\tau-14-S_j\right)-1\right), \tag{4.1}$$

where the first term on the right-hand side is the growth rate of skill prices, and the other two terms represent the growth rate of human capital due to the accumulation of experience. In order to obtain a smooth profile of skill prices we specify $\ln\left(w^j_{t+1}/w^j_t\right)$ as a cubic polynomial in time.

The growth rate of average earnings between periods t and $t+1$ for a given cohort τ of agents is assumed to be measured with error:

$$e^j_{t+1\tau} = \ln \frac{w^j_{t+1}\overline{h}^j_{t+1\tau}}{w^j_t\overline{h}^j_{t\tau}} + u^j_{t+1\tau} \tag{4.2}$$

where $e^j_{t+1\tau}$ denotes the observed growth rate between t and $t+1$ of average earnings among workers in cohort τ with education level j, and $u^j_{t+1\tau}$ is the classical measurement error. Replacing the cubic polynomial in time and equation (4.1) into equation (4.2) yields the regression equation we estimate:

$$e^j_{t+1\tau} = \delta^j_1 + \alpha^j_0 + \alpha^j_1 t + \alpha^j_2 t^2 + \alpha^j_3 t^3 + \delta^j_2\left(2\left(t-\tau-14-S_j\right)-1\right) + u^j_{t+1\tau}, \tag{4.3}$$

where α^j_k, for $k = 0-3$, are the parameters of the cubic polynomial and the first year in the data, 1949, is normalized to equal $t = 0$.

Several remarks are in order. First, as can be noticed from the regression equation above, δ^j_1 is not separately identified from the constant term α^j_0 in the cubic polynomial. We identify δ^j_1 in Section 4.1.3 by requiring the model to match a number of additional moments. Second, the parameter δ^j_2 and the four coefficients of the cubic polynomial can be identified and estimated using ordinary least squares on the sample of observed growth rates of earnings over time for different cohorts. We run a separate regression for each schooling level. Notice that, differently from δ^j_1, the parameter δ^j_2 can be identified because slower earnings growth for an older cohort with the same schooling level between two periods cannot be explained by the common evolution of skill prices. Instead, if (say) the earnings profile is concave ($\delta^j_2 < 0$), the older cohort must have smaller earnings growth than the younger one.[27]

Third, the structure of the data underlying equation (4.3) is an unbalanced panel of earnings growth by cohorts over time. The unbalanced nature of the panel comes from the fact that, consistently with our model, individuals stop working at age 65 and four-year college graduates start working at age 23. The dependent variable $e^j_{t+1\tau}$ is constructed as the weighted (by weeks worked) average of weekly earnings of full-time full-year white males in a given cohort τ with schooling level j who are between 23 and 65 years old in the year to which the earnings question in the data survey refers to. The data surveys are the 1950 and 1960 Census and the 1964–2010 CPS.[28] Thus, even if our goal is to explain the attainment

[27]The point estimates of the curvature parameters δ^j_2 are reported Appendix D. They are all negative, which is consistent with a hump-shaped profile of earnings over the life-cycle.

[28]The earnings sample is the same as the one used to produce Figure 2, and is described in Appendix

data for the 1932–1972 cohorts, in order to estimate the parameters in equation (4.3), we include individuals who belong to the cohorts 1884–1986 as long as they satisfy the sample selection criteria. This approach, which is consistent with our theoretical setup, allows us to increase the number of data points used to estimate the growth rate of skill prices over time. The sample used to estimate equation (4.3) has 2,623 cohort-time observations for each schooling level j.

Figure 4 displays the series of skill prices relative to the skill price associated with a high-school diploma, or w_t^j/w_t^3, across calendar years. These ratios are normalized to take a value of one in 1949.[29]

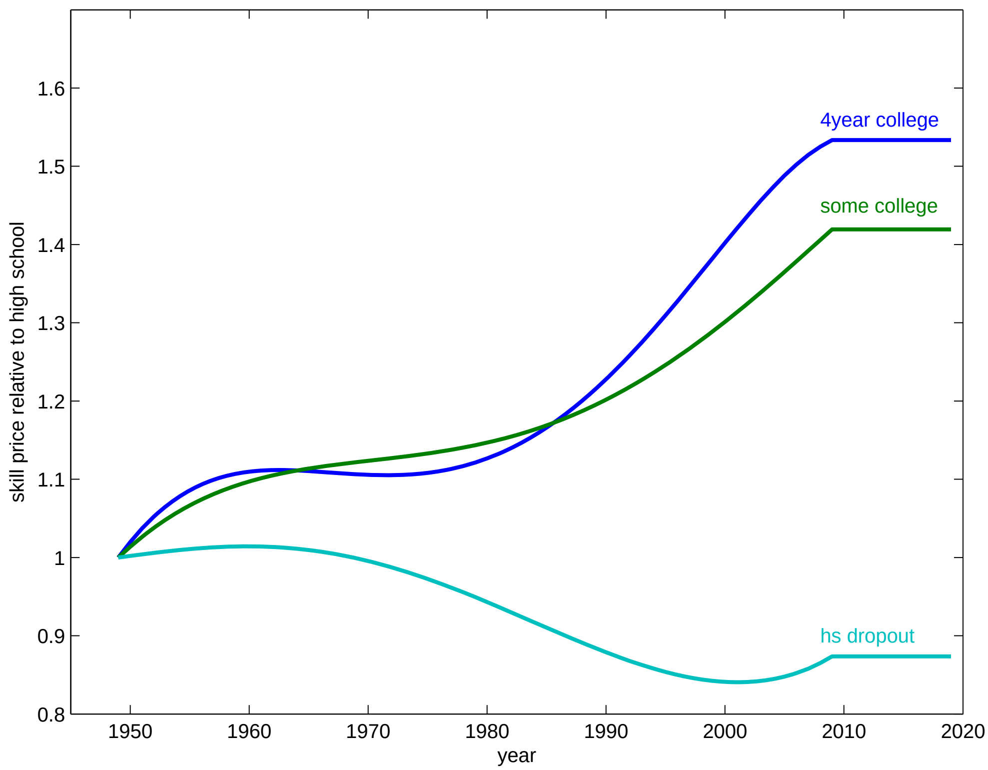


Figure 4: Skill Prices (relative to high school)

The evolution of the estimated skill prices is qualitatively consistent with the evidence presented in Figure 2. Specifically, the dynamics of the relative skill price associated with a four-year college degree may be summarized in three subperiods. First, it increases relative to high school in the 1950's and early 1960's. Second, it declines starting in the mid-1960's

C.2.2. Notice that since the Census earnings data refer to the years 1949 and 1959 we assume a constant growth rate of earnings for each cohort and education level in that decade. This assumption plays no role in our results.

[29] As mentioned in the text, the skill price series cannot be estimated completely outside of the model because in the regression (4.3) only the sum $\delta_1^j + \alpha_0^j$ is identified and not the two components individually. To compute the series of skill prices we need to calibrate the full model (see Step 3).

and during the 1970's. Third, after the year 1980, the relative skill price of individuals with a four-year college degree increases dramatically.

4.1.2 Step 2 - Parameters Set A-Priori

In this section and the next we describe how we set the functional forms and the remaining parameters of the model. Our strategy is to set some parameters a-priori based on available evidence and calibrate the rest in order to match some key features of the data. The parameters set a-priori are as follows:

- Life-span: $L = 50$. Since in the model individuals begin life at age 15 they are assumed to retire at age 65.
- Gross real interest rate: $R = 1.05$. A standard value, and the one used by Heckman, Lochner, and Taber (1998).
- Discount factor: $\beta = 1/R$.
- Labor income tax-rate: $\lambda = 0.15$. This is the income tax rate from Heckman, Lochner, and Taber (1998), who in turn borrow it from Pechman (1987).[30]
- Curvature of human capital accumulation technology during schooling period: $\gamma = 0.85$. This is consistent with the values estimated by Heckman, Lochner, and Taber (1998) and employed by You (2011).[31]
- Depreciation rate of human capital accumulation technology: $\mu = 0$, consistent with Heckman, Lochner, and Taber (1998) and You (2011).
- The parameter ϕ is set 0.06, as estimated by You (2011).
- Psychic cost of high-school dropouts is normalized to zero without loss of generality: $\overline{\xi}^4 = 0$.
- The initial human capital is normalized to one without loss of generality: $h_1 = 1$.
- The distribution of ability is lognormal: $\theta \sim LN(\mu_\theta, \sigma_\theta)$ with mean μ_θ normalized to one without loss of generality and standard deviation σ_θ.

[30] We assume a constant tax rate to give the model the best chance to replicate the dynamics of educational attainment. Later cohorts in our sample have in fact experienced lower marginal tax rates, which should have increased their incentive to obtain education.

[31] Computations we have performed and that are not shown, suggest that our results are not sensitive to a specific choice of γ in the range $[0.5, 1]$.

4.1.3 Step 3 - Calibration of Remaining Parameters

We calibrate the thirteen remaining parameters $\left(\sigma_\theta, \sigma, \{\bar{\xi}^j\}_{j=1}^3, \{w_0^j\}_{j=1}^4, \left\{\delta_1^j\right\}_{j=1}^4\right)$ by targeting the fifteen moments listed below, involving educational attainment levels, education earnings premiums, and within-group earnings inequality for the 1932 and 1972 cohorts. We do not include in the calibration any moment related to the educational attainment of the 1933–1971 cohorts because we want to use these data to evaluate the performance of the model.

Notice that this part of the calibration procedure involves: (i) solving the decision problem of the agents in cohorts 1932 and 1972 for a given vector of the thirteen parameters listed above;[32] (ii) computing the moments implied by the model; (iii) repeating this procedure by updating the vector of parameters to minimize the sum of squared percentage deviations between model and data moments.

In solving the decision problem we assume that individuals expect skill prices to remain constant at the 2009 level when their working life extends beyond 2009. Any growth in earnings after that date comes only from the experience profile. Notice that post-2009 prices are only relevant for the decision of a few of the later cohorts. Also, given the fact that the last cohort we study was born in 1972 and that future earnings are discounted, this assumption is fairly innocuous.

The fifteen moments targeted by the calibration procedure are:[33]

1.-2. Share of workers in the 1932 and 1972 cohorts with (only) a high school degree by age 23: AR_τ^3 for $\tau = 1932$ and 1972. The empirical counterparts of these moments are 0.4606 and 0.3690 respectively.

3.-4. Share of workers in the 1932 and 1972 cohorts with some (1–3 years) college by age 23: AR_τ^2 for $\tau = 1932$ and 1972. The empirical counterparts of these moments are 0.2240 and 0.3263.

5.-6. Share of workers in the 1932 and 1972 cohorts with a four-year college degree by age 23: AR_τ^1 for $\tau = 1932$ and 1972. The empirical counterparts of these moments are 0.1451 and 0.2308.

[32] For each set of $\left\{\delta_1^j\right\}_{j=1}^4$ parameters we use the estimates of $\left(\alpha_0^j + \delta_1^j\right)$ from Step 1 to infer the parameters α_0^j that determine the evolution of skill prices. Thus, the estimated series of skill prices is updated as part of the calibration procedure.

[33] Notice that all the moments involving earnings are computed using our earnings sample in order to minimize biases from composition effects. The attainment numbers, instead, are based on the broader sample underlying Figure 1. See Appendix C.2 for a description of these samples.

7.-8. High school dropout earnings premium (relative to high school graduation) among 27 year old workers in the 1932 and 1972 cohorts: $EP^{4,3}_{\tau,\tau+27}$ for $\tau = 1932$ and 1972. The empirical counterparts of these moments are 0.9261 and 0.7485.

9.-10. Some college earnings premium (relative to high school graduation) among 27 year old workers in the 1932 and 1972 cohorts: $EP^{2,3}_{\tau,\tau+27}$ for $\tau = 1932$ and 1972. The empirical counterparts of these moments are 1.0650 and 1.1084.

11.-12. Four-year college graduation earnings premium (relative to high school graduation) among 27 year old workers in the 1932 and 1972 cohorts: $EP^{1,3}_{\tau,\tau+27}$ for $\tau = 1932$ and 1972. The empirical counterparts of these moments are 1.1546 and 1.5741.

13. Cumulative earnings growth observed between 1959 and 2009 for workers in all cohorts between 1932 and 1972 who are participating in the labor market.[34] The ratio between real earnings in 2009 to real earnings in 1959 is 1.9928 in the data.

14. Standard deviation of log weekly earnings among 27 year old workers with a four-year college degree in the 1932 cohort. The empirical counterpart of this moment is 0.3550.

15. Ratio between the present value of four-year college tuition faced by individuals in the 1932 cohort and the average earnings of high-school dropouts by members of this same cohort in their first year of work. This ratio is equal to 0.8772 in the data.[35]

The key to our calibration strategy is matching the education attainment levels and earnings premia for the first and the last cohorts in the sample. The associated moments are informative for the utility cost parameters $\{\overline{\xi}^j\}_{j=1}^3$, the returns to experience parameters $\left\{\delta_1^j\right\}_{j=1}^4$, and the level of skill prices $\{w_0^j\}_{j=1}^4$. The elasticity of educational attainment to variation in skill prices is governed by the parameter σ, so this parameter is identified by the variation in educational attainment between the 1932 and the 1972 cohorts. The extent of cross-sectional earnings inequality among individuals with a college degree is informative for the parameter σ_θ determining the dispersion in innate learning abilities.

[34] The choice of 1959 as first year reflects the fact that the 1950 Census provides data for 1949, but at that time only high school dropouts of the 1932 cohort were active in the labor market. The next set of data comes from the 1960 Census, hence our choice of 1959 as the initial year for this moment.

[35] For the 1932 cohort, one year of four-year college tuition therefore amounts to roughly one-fifth of the annual earnings of high-school dropouts. Notice that while the present value of four-year tuition refers to the year 1951 (i.e. the time when the 1932 cohort entered college), the fact that the earnings data are available only in the decennial Census forces us to compute the average earnings of high school dropouts in the year 1949. This small discrepancy has no bearing in our results, indeed we compute the exact same ratio in the model.

The calibrated parameters are listed in Table 1, together with the parameters set a-priori.[36]

L	β	R	γ	μ	h_1	λ	$\overline{\xi}^4$	μ_θ	ϕ
50	0.95	1.05	0.85	0.00	1.00	0.15	0.00	1.00	0.06

(a) Parameters Set A-Priori

σ	σ_θ	$\overline{\xi}^1$	$\overline{\xi}^2$	$\overline{\xi}^3$	w_0^1	w_0^2	w_0^3	w_0^4
4.6659	0.1316	−0.0320	−0.7425	−0.9757	0.0159	0.0411	0.1325	0.3827

(b) Calibrated Parameters

δ_1^1	δ_1^2	δ_1^3	δ_1^4
0.0668	0.0585	0.0517	0.0494

(c) Calibrated Parameters (cont.)

Table 1: Benchmark calibration

Table 2 summarizes the moments used to calibrate the parameters and their predicted values. Overall, the model matches the fifteen moments very well.

4.2 Educational Attainment and Returns to Schooling for the 1932 and 1972 Cohorts

In order to understand the mechanics of the model it is useful to discuss its predictions for the educational attainment of the 1932 and 1972 cohorts used in the calibration (Section 4.2). Figure 5 illustrates the basic mechanisms underlying the selection of heterogeneous individuals across different schooling levels and how changes in the driving forces of the model over time have led to changes in educational attainment. Among these forces, skill prices play a quantitatively pre-eminent role (from further analysis not shown here).

Figure 5a presents the ratio of earnings at age 27 for an individual of ability θ who chooses education level j relative to the earnings at the same age of an individual of the same ability with a high school degree ($j = 3$).[37] For each j, the solid line corresponds to the 1932 cohort while the dashed line aligned with it corresponds to the 1972 cohort. Figures 5b and 5c present the proportion of individuals who choose each schooling level $j = 1 - 4$ as

[36] While most of these parameters are model-specific and are not directly comparable with the literature, the estimated age-earnings profiles by education group are consistent with returns to experience being steeper for more highly educated individuals. We report them in Appendix D together with the estimates of $\left\{\delta_2^j\right\}_{j=1}^4$.

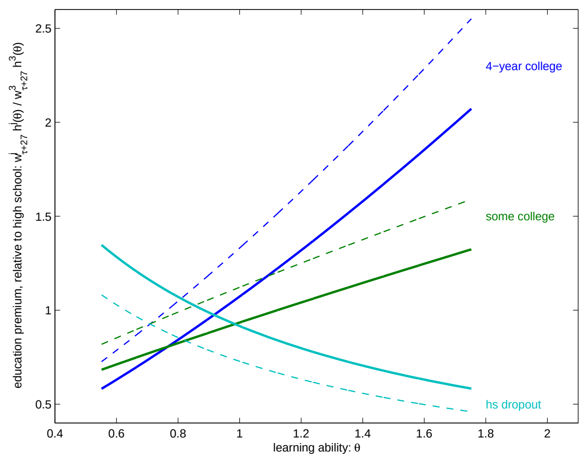
[37] Formally, we plot the ratios $w_{\tau+27}^j h^j(\theta) / w_{\tau+27}^3 h^3(\theta)$ against θ for the cohorts $\tau = 1932$ and 1972, so we implicitly control for the differential experience associated with each education choice.

Moments	Data	Model
Educational attainment, 1932 cohort		
1. High school	0.4606	0.4605
2. Some college	0.2240	0.2271
3. Four-year college	0.1451	0.1432
Educational attainment, 1972 cohort		
4. High school	0.3690	0.3689
5. Some college	0.3263	0.3215
6. Four-year college	0.2308	0.2336
Education premiums (relative to high school), 1932 cohort		
7. High school dropout	0.9261	0.9301
8. Some college	1.0650	1.010
9. Four-year college	1.1546	1.2018
Education premiums (relative to high school), 1972 cohort		
10. High school dropout	0.7485	0.7476
11. Some college	1.1084	1.1607
12. Four-year college	1.5741	1.4973
13. Earnings in 2009 relative to 1959, four-year college (all cohorts)	1.9928	1.9838
14. Std deviation log weekly earnings, 1932 cohort, four-year college	0.3550	0.3561
15. Present value of 4 year college tuition relative to earnings of high school dropout in 1949	0.8772	0.8800

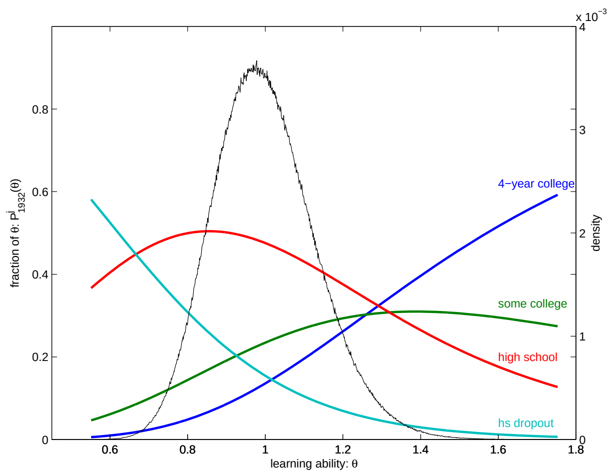
Table 2: Targeted Moments

a function of ability for the 1932 and 1972 cohorts, i.e. $P^j_{1932}(\theta)$ and $P^j_{1972}(\theta)$, together with the population density of abilities, which is assumed to be the same for all cohorts.

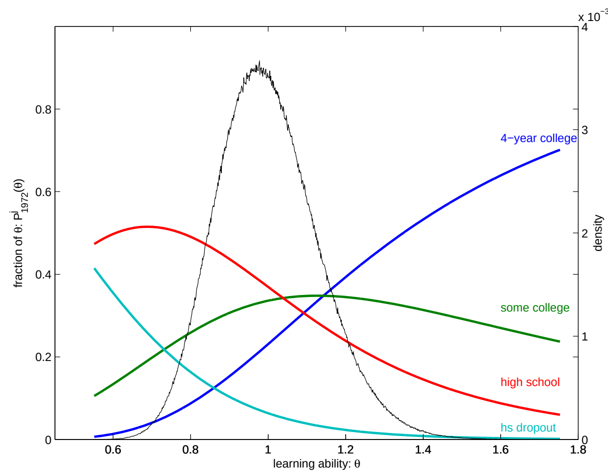
From Figure 5a we gather, for example, that low ability individuals at age 27 earn more as high school dropouts than they would have earned as high school graduates. Consistently, Figures 5b and 5c show that the probability of dropping out of high school is highest among low ability agents. The specific way selection occurs in the model is as follows. Skill prices are the highest for high school dropouts. This benefits mostly low ability individuals, who start with relatively low human capital and are unable to accumulate a lot of it over time. High ability individuals, instead, can accumulate large amounts of human capital, and this positive quantity effect dominates the negative skill price effect of attaining a higher degree. More generally, as stated in Proposition 2, for any two education levels, the fraction of individuals choosing the highest one increases with ability. As a corollary, ability selection is stronger for the lowest and the highest degrees, with a very high propensity of low ability types to drop out of high-school, a very low propensity of high types to do the same, and the reverse for four-year college programs.



(a) Education earnings premia by ability, 1932 cohort (solid) vs 1972 cohort (dashed)



(b) Attainment by ability, 1932 cohort



(c) Attainment by ability, 1972 cohort

Figure 5: Returns to schooling and attainment in the model, 1932 and 1972 cohorts

Individuals who belong to different cohorts but have the same ability and preference shocks make different education choices because they face different streams of skill prices, tuition and education expenditures. Figure 5a shows an increase over time in the returns to a four-year college degree, for all ability levels. Consequently, in Figures 5b and 5c we observe an increase in the fraction of individuals with a four-year college degree in the 1972 cohort relative to the 1932 one.[38] Comparing these two figures we observe that all ability levels

[38]Recall that the model's parameters are calibrated to match the magnitude of the increase in four-year college attainment between these two cohorts.

increase their four year college attainment in 1972 relative to 1932. However, the increase is more pronounced for the higher ability types. That is we observe a stronger selection into college by ability as the monetary reward from this choice went up. The net effect on average ability of college and high school graduates is, therefore, in principle ambiguous. Based on the model's results, average ability falls within each group, but the decline is larger for the high school group leading to an increase in the relative ability of a college graduate in 1972.

The model predicts an increase between the 1932 and 1972 cohorts in the observed gap between college and high school earnings at age 27 from 1.2 to 1.5, or a factor of 1.25. According to Figure 4, the skill price of college relative to high school increased from about 1.11 in 1959 (the year when the 1932 cohort turn 27) to 1.38 in 1999 (the year when the 1972 cohort turn 27). Hence, the increase in skill prices predicts that the college premium should have increased by a factor of 1.24, which is less than the actual increase generated by the model. The discussion above suggests that the changing nature of selection into college explains this discrepancy.

We now turn to discuss the implications of the model for the educational attainment of the cohorts between 1932 and 1972.

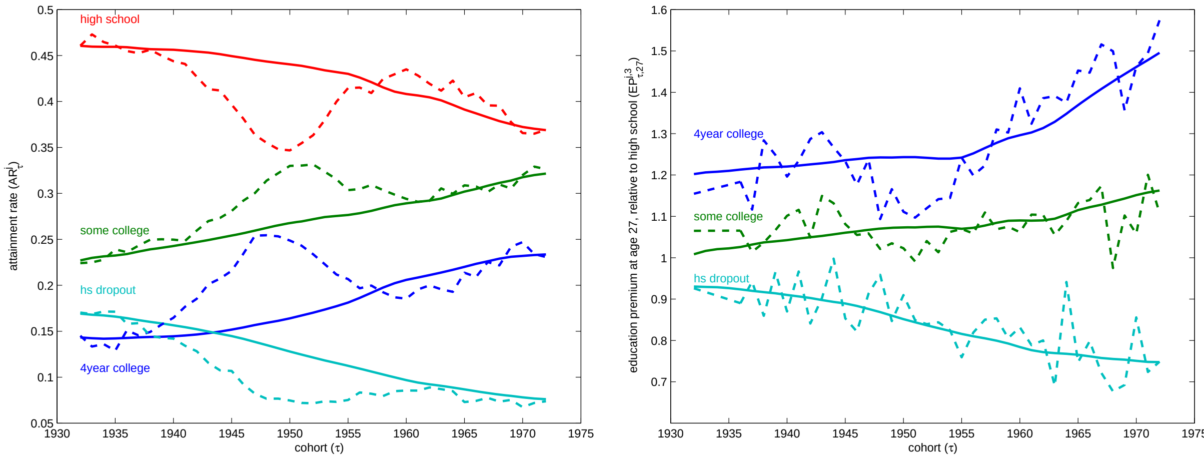
5 Results

In Section 5.1 below we discuss the predictions of the model for the educational attainment of the $1933 - 1971$ cohorts, whose educational attainment the model does not match by construction. In the subsequent sections we first recalibrate the model and evaluate its performance under the assumption of myopic expectations over skill prices, and then evaluate the contribution of changes in school quality, tuition, and the rate of growth of skill prices to the performance of the benchmark model.

5.1 Performance of the Benchmark Model

We evaluate the performance of the model based on its ability to account for the evolution of educational attainment for the cohorts 1933–1971. Figure 6a displays educational attainment and education premiums (at age 27) by birth cohort in the data and in the model.

Consider, four-year college attainment first. Notice that, while the model fits the four-year college attainment rates for the 1932 and the 1972 cohorts by construction, it fails to account for the evolution in between. The largest increase in attainment in the data is between the 1932 and the 1948 cohorts. Attainment increases by 0.68 percentage point per cohort for these cohorts. After that, four-year college attainment *declines* until the 1960



(a) Attainment

(b) Education Premiums

Figure 6: Accounting for the data; benchmark model (solid) vs data (dashed)

cohort at a pace of 0.57 percentage points per cohort. Finally, attainment recovers at the relatively slow pace of 0.38 percentage point per cohort, but for the 1972 cohort it remains more than two percentage points below its previous peak.

The model predicts an almost opposite pattern, displaying the slowest growth in attainment from the 1932 until the 1948 cohort, at a pace of 0.10 percentage points per cohort; the fastest growth between the 1948 and 1960 cohorts at a pace of 0.39 percentage points per cohort; and an intermediate growth for the post-1960 cohorts at a pace of 0.23 percentage points per cohort. Notice that the model, differently from the data, does not predict an absolute decline in attainment between the 1948 and 1960 cohorts.

The behavior of attainment in the model is largely driven by the dynamics of skill prices in Figure 4. The skill prices mostly relevant for the schooling decisions of the 1932–1948 cohorts are the 1949–1980 ones, and the four-year college skill price increases by only 13 percent relative to its high school degree counterpart between these two dates. This translates into a relatively flat four-year college attainment predicted by the model over these early cohorts.[39] The middle cohorts 1949-1960 enjoy the relative low tuition of the 1970s while anticipating the rise in the college premium in the 1980s and display a fast rise in their college attainment. By contrast the later post-1960 cohorts, anticipate a growing college premium but also face higher tuition.

The second dimension along which we evaluate the model is the attainment dynamics associated with the remaining education levels. The fraction of individuals with some college

[39]Notice that the baseline assumption of perfect foresight further contributes to smooth out temporary movements in skill prices such as the decline of the relative four-year college skill price during the 1970's. We address alternative formulations of expectations in Section 5.3.

grows steadily according to the model while it displays a pattern analogous to the one of four year college in the data. The skill prices associated with some college are similar to those associated with a four year college. Finally, the model predicts a smooth decline in the fraction of people who are high school dropouts. This smooth decline is driven by a smooth decline in the relative skill price of high school dropouts. In the data, instead, the decline in this category is very sharp up to the 1948 cohort. Afterwards, the proportion of the population who drops out of high school is fairly constant.

In the right panel of Figure 6a we plot the predictions of the model for the observed education premiums (relative to high school). The model correctly predicts a more rapid increase in the college premium for the cohorts born after 1955 who turned 27 starting in the early 1980s than for the earlier cohorts. However, it misses the decline in the college premium in the 1970s (i.e., for the cohorts who turned 27 in those years) and slightly underpredicts the overall increase in the college premium across cohorts. The fit of the two-year college and high school dropout education premium series is, instead, very good.

In order to better understand the importance of the different components of the model in generating these results, in what follows we perform two kinds of experiments. First, in Section 5.2 we feed into the benchmark model counterfactual series for education expenditures, tuition and skill prices and assess the extent to which the predictions of the model change. Second, in Section 5.3 we relax the assumption of perfect foresight, recalibrate the model's parameters, and evaluate its fit of the attainment data.

5.2 The Roles of Tuition, Education Quality and Skill Price Growth

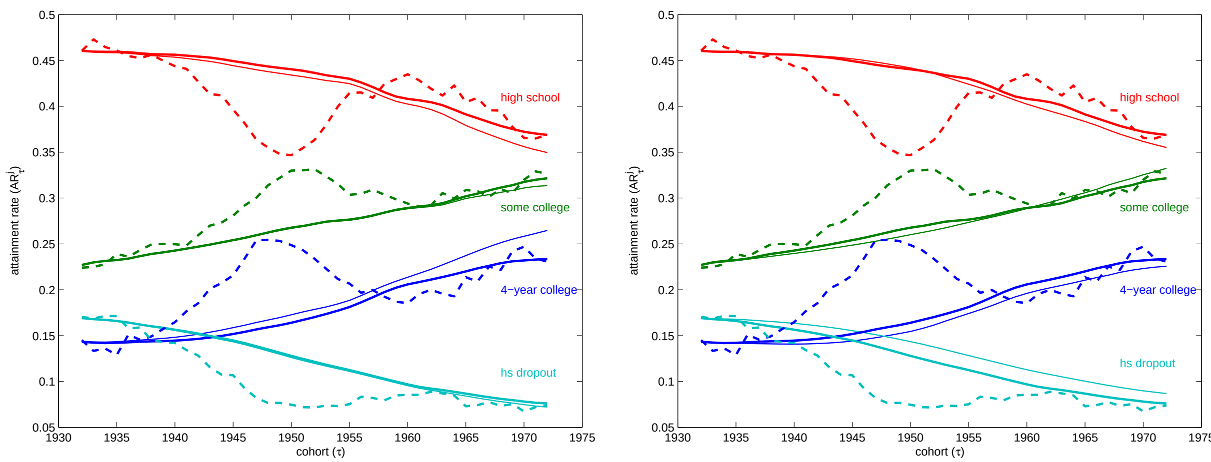
5.2.1 Tuition Costs

We isolate the role of tuition by imposing that its present value remains constant at the level faced by the 1932 cohort, that is $Z^j_\tau = Z^j_{1932}$ for all τ and $j = 1, 2$. We then trace out the attainment dynamics implied by the benchmark model. The parameters, as well as the evolution of skill prices and schooling quality are the same as in the benchmark case.

Figure 7a presents the results. Not surprisingly, the most significant effect is on four-year college attainment. Without the increase in tuition displayed in Figure 3a, four-year college attainment would have risen faster, especially for the later cohorts. This accounts in part for the fact that the post-1960 cohorts exhibited a slower increase in college attainment in the model relative to the 1948-1960 cohorts.

A natural question is whether the implied elasticity of attainment to changes in tuition is consistent with the empirical evidence. The answer is affirmative, but the implied elasticity is at the low end of what has been estimated in the literature reviewed by Kane (2006). He reports a range of estimates about the effect of $1,000 (1990 dollars) increase in tuition on college enrollment (not attainment). The studies occurred in periods between the late 1980s and the late 1990s, where average tuition varied between $3,000 and $4,000 (in 1990 dollars), so the $1,000 figure represents a 25-33 percent increase in tuition. The range of impact is between 2 and 5 percentage points decline in enrollment per $1,000 dollar. Between 1951 and 1991 tuition increased by 160 percent in real terms. Taking the 33 percent and 2 percentage points figures as our favorite estimates, this implies a predicted reduction in *enrollment* of 10 percentage points. Our results imply that the 160 percent increase in tuition reduces four year college *attainment* in the 1972 cohort by about 4 percentage points.

The elasticity of attainment to tuition is relatively small because the model abstracts from credit constraints.[40] Their importance for college attainment of individuals from low-income households is debated in the literature (for alternative views see e.g. Kane (1999) and Carneiro and Heckman (2002, 2003)).



(a) Constant tuition

(b) Constant schooling quality

Figure 7: Role of tuition and school quality; benchmark (thick), experiment (thin), and data (dashed).

5.2.2 Changes in Education Quality

Figure 7b shows the predictions of the model for educational attainment when each cohort faces the same path of education expenditures as the initial one (i.e. the 1932 cohort). Most of the effects of expenditures are concentrated on the fraction of high school dropouts and high school graduates. The fraction of high school dropouts would have been larger

[40]The conclusion about the effects of tuition on attainment in the absence of credit constraints is similar to the one reached by Jones and Yang (2011) in the context of a general equilibrium model of investment in education in which the cost of college evolves endogenously over time.

and the fraction of high school graduates smaller had education expenditures remained constant. Allowing for variation in education expenditures tends to increase four year college graduation.

5.2.3 Constant Skill Price Growth

Keller (2013) argues that the slowdown in college attainment can be explained by variation over time in the growth rate of skill prices. Specifically, for given relative prices, a generalized decline in their growth rate would cause a decline in college attainment by increasing the opportunity cost of investment in schooling relative to the final pay-off. This effect is also present in our benchmark model with perfect foresight and, as such, it cannot explain the evolution of college attainment over time. We evaluate its impact on our results by feeding into the model a counterfactual series of skill prices in which the skill price of high school is forced to evolve at a constant rate over time between 1949 and 2009, while the *relative* skill prices of the other education levels change over time as in the benchmark. The results are presented in Figure 8.

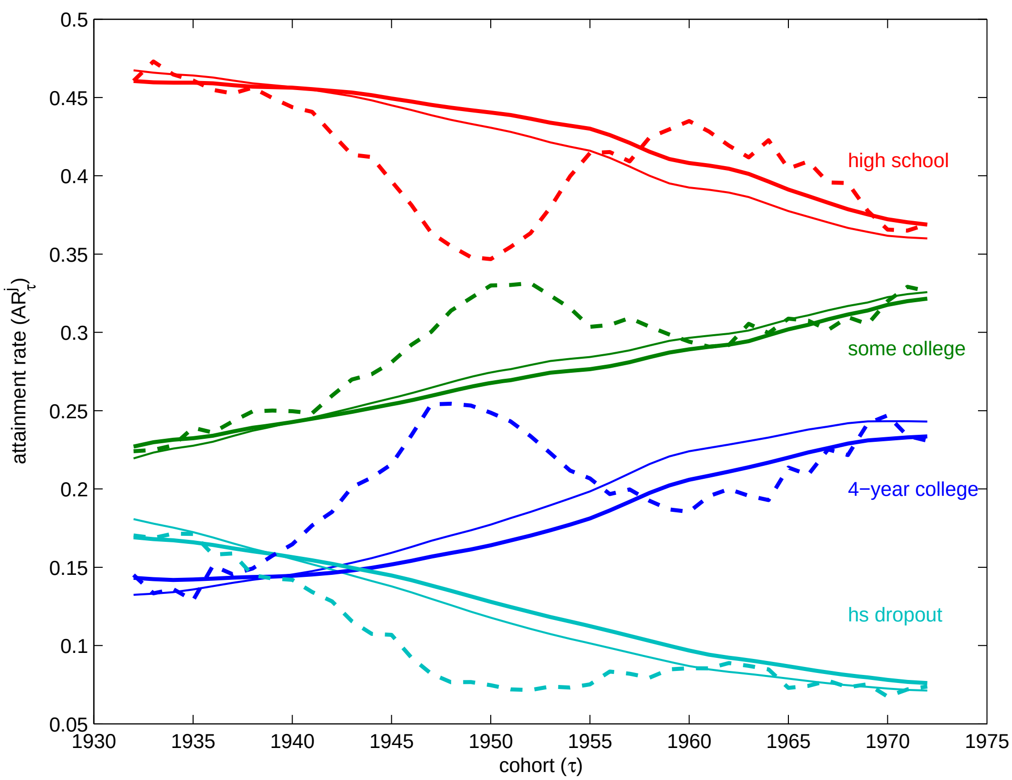


Figure 8: Constant skill price growth; benchmark (thick), experiment (thin), and data (dashed)

The figure shows how the effect emphasized by Keller (2013) operates in the direction of increasing college attainment (both four and two year college) for the very early cohorts (up to about 1940) and decreasing it for the later ones. This is due to the fact that in our model skill prices grew, on average, faster in the very early part of the sample period than later on. The magnitude of this effect appears to be relatively small.

5.2.4 Decomposition of Results for Four-Year College

In this section we summarize the contribution of the driving forces discussed above to the change in four-year college graduation rates by birth cohort predicted by the model. Specifically, after calibrating the model to match key moments for the 1932 and 1972 cohorts, we switch on each driving force in a sequential way, starting from the change in relative skill prices while keeping constant the growth in the high school skill price. We then allow for time variation in the growth of skill prices; then introduce the change in education expenditures; and finally the change in the present value of tuition. The results are reported in Table 3 in the form of percentage points average attainment gains (+) or losses (−) per cohort attributable to each factor.[41]

	Cohorts		
	1932 − 48	1948 − 1960	1960 − 1972
Data (ppts. per cohort)	0.68	−0.57	0.38
Model			
No change	0.00	0.00	0.00
Add change relative skill pr.	+0.24	+0.44	+0.39
Add change growth skill pr.	−0.17	−0.14	−0.02
Add change in ed. exp.	+0.08	+0.09	+0.06
Add change in tuition	−0.05	0.00	−0.19
Benchmark model	0.10	0.39	0.23

Table 3: Contribution to the change in four-year college attainment of the model's driving forces.

The results of this analysis are consistent with the discussion in the previous sections. Quantitatively, relative skill prices have the strongest effect on the evolution of attainment for each group of cohorts. However, as noted in Section 5.1, relative skill prices alone predict a faster growth in college attainment for the 1948-60 and 1960-72 cohorts than for the 1932-48 ones, while the data clearly shows the opposite pattern. The second element, the overall

[41] While the order in which we perform the decomposition matters for the figures in Table 3, the relative quantitative importance of each driving force does not depend on the exact ordering.

growth in skill prices keeping constant their relative magnitudes, tends to depress college attainment for all groups of cohorts, especially the early ones. The evolution of education expenditures favors college graduation, especially for the earlier cohorts. Tuition plays a role only for the 1960-72 cohorts, by significantly reducing their attainment.

5.3 The Role of Expectations

The assumption of perfect foresight is obviously strong, as it endows agents with the ability to predict shifts in trends of skill prices that are largely unexpected to researchers and policymakers. As an example, in the 1970s the academic debate on college attainment centered around the issue of whether Americans were "overeducated" (Freeman, 1976).

In this section we assume that agents' expectations are "myopic". Specifically, we postulate that agents in cohort τ make their schooling plans by assuming that skill prices will remain constant at the level they observe when they are about to make their schooling decisions. In practice, we suppose they rely upon skill prices at age seventeen, $w^j_{\tau+17}$.[42] This is the age in the model when individuals decide whether to dropout of high-school.

Given the way we measure skill prices in the data, based on cross-sectional information, our assumption is akin to supposing agents base their schooling decisions on the contemporaneous cross-sectional wage gaps. This is the assumption entertained by Card and Lemieux (2001a) and Topel (1997).[43]

We make the following two ancillary assumptions, which allow us to simplify our analysis and concentrate on the role of skill price expectations: (i) individuals commit to schooling decisions based on the perceived prices, and cannot change their choices later on when new information becomes available;[44] and (ii) individuals are able to perfectly forecast the tuition and schooling quality levels that will be relevant for their own schooling choices.

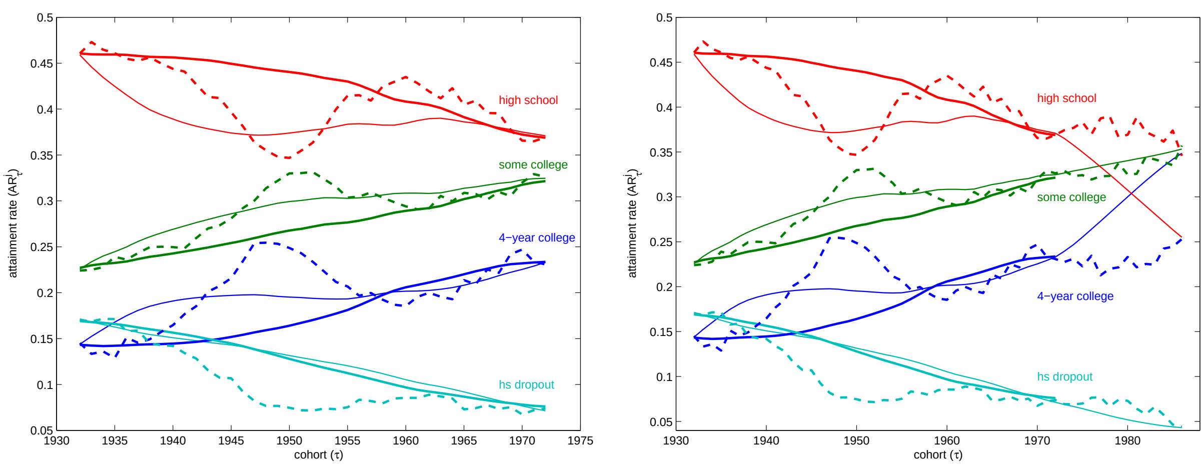
We recalibrate the model's parameters for this version of the model by matching the same data, and summarize them in Table 5 in Appendix E. Both model versions are similarly successful in matching the targeted moments (Table 6). As Figure 9a suggests, the myopia version of the model performs better than the perfect foresight one. Specifically, the version

[42]We use prices at age 17 (rather than 15, which would correspond to $l = 1$) because the earliest observations on earnings are from the 1950 Census and refer to the calendar year 1949 (which equals 1932 plus 17). Using prices at age 17 therefore allows us to treat all cohorts symmetrically regarding their expectation formation.

[43]A related assumption is also made by Willis and Rosen (1979), where agents need to forecast individual-specific but time-invariant growth rates of future earnings. Willis and Rosen (1979) are primarily interested in the role of differences in "long-run" earnings expectations in explaining schooling decisions of different individual types, a cross-sectional feature. Our focus is instead on how changes in expectations across cohorts may contribute to understanding changes in schooling choices.

[44]Planned consumption decisions will instead differ from actual ones, depending on the skill price realizations. Our ancillary assumption ensure this won't affect schooling decisions.

with myopia captures about half of the increase in attainment for the 1932-1948 cohorts, predicts a flat attainment profile between the 1948 and the 1960 cohort, and a subsequent mild increase for the post 1960 cohorts. Notably, the latter increase is smaller on average than the initial rise displayed by the 1932-1948. While this version of the model is more consistent with the data than the benchmark, a closer inspection suggests that it also does not provide a satisfactory account of attainment. The reason is that a myopic agent bases its decisions on skill prices at age 17, so an agent born in the 1972 cohort bases its choice on the 1989 skill prices. However, according to our estimates (see Figure 4), the relative skill price of college continues to increase past 1989 in a significant way. The myopia model would then predict, counterfactually, a large increase in four year college attainment for the post 1972 cohorts. To verify this conjecture we use the calibrated model with myopia to predict the evolution of educational attainment for the cohorts 1973–1986. The results are shown in Figure 9b. They confirm that the model with myopia, calibrated to match the educational attainment of the 1972 cohort, tends to overpredict the rise in college attainment for the post-1972 cohorts.[45]



(a) Until 1972 cohort

(b) Beyond 1972 cohort

Figure 9: Role of myopia; benchmark (thick), myopia (thin), and data (dashed)

6 A Suggested Interpretation

The analysis in the previous sections presents us with a puzzle. In our view, the evolution of educational attainment for the cohorts we focus on cannot be explained by the driving

[45] An additional exercise we have implemented is to calibrate the model with myopia to match moments for the 1982 (instead of 1972) cohort. This version, whose results are not reported, fares better than the one in Figure 9b, but tends to underpredict college attainment for the cohorts after 1960.

forces we have considered: the evolution of skill prices, tuition, and education expenditures. Myopia in the decision making process does not resolve the puzzle either. In this section we present and discuss what we think is a useful approach to its resolution. The key feature of this approach is the joint consideration of *all* levels of educational attainment, from dropping out of high school to graduation from a four-year college. Our hypothesis is that a theory that successfully explains the evolution of high school dropout rates is also likely to be successful in accounting for the evolution of college attainment. The educational attainment data in Figure 1 are consistent with this view. Notice how the 1948 cohort marks not only the peak in four-year college attainment in our sample, but also the bottom in high school dropout rates. The stagnation in college attainment for subsequent cohorts has its counterpart in the stagnation of high school dropout rates.[46] This points to the possibility that cohort-specific factors play an important role in accounting for the evolution of educational attainment.

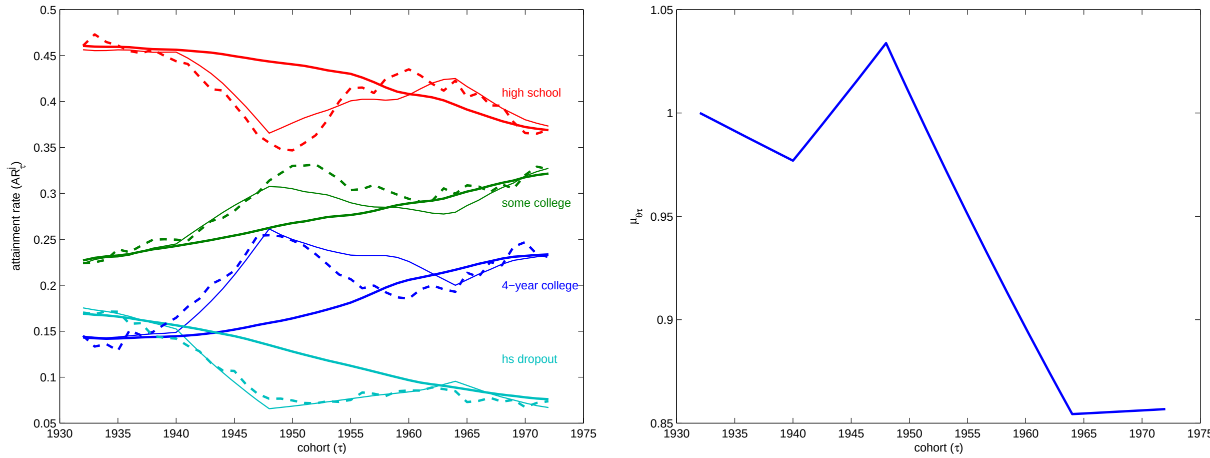
In this section we investigate one of these factors by letting the mean parameter of the distribution of ability vary by cohort. This assumption is not inconsistent with the empirical evidence on the Flynn effect, i.e., the observation that IQ test scores have been increasing over subsequent cohorts starting from the 1930's. Flynn (2007) presents evidence for the U.K. showing a decline in IQ scores of the average 14 year old between 1980 and 2008. Possible reasons for variation in mean ability by cohort are biological/environmental or socio-economic, given that from the perspective of our model the parameter θ is measured at age 15. A candidate explanation is the evolution of the family structure in the U.S. For example, (Heckman, 2008, Figure 3) reports a dramatic increase in the percent of children less than five with never married mother starting in the 1960s.

We "tie our hands" by calibrating the new parameters governing the evolution of mean ability, μ_θ, across cohorts to match high school dropout rates by cohort. The performance of the model is then evaluated based on its ability to account for the evolution of the other levels of educational attainment.[47] A parsimonious piecewise linear specification of μ_θ as a function of τ is sufficient to match the evolution of the high school dropout rate very closely.[48]

[46]Notice that there is no mechanical way in which these two series are related.

[47]In principle, there are a number of parameters that may be varied to target the evolution of the high school dropout rate. Notice, however, that only changes in parameters that affect college and high school graduation education rates in the same direction have the potential to account for the evolution of college attainment. For example, one could let the utility cost of graduating from high school (denoted by $\bar{\xi}^3$) decline for the 1932-1948 cohorts to target the decline in the high school dropout rate. This change, however, would also lead to a reduction in college graduation, which is inconsistent with the data. This observation reduces the set of parameters might be allowed to vary by cohort to explain the data.

[48]The piecewise linear functional form has four parameters (see appendix E). To calibrate them we add three more moments to the list in Table 2: the high school dropout rate of the 1942, 1952, and 1962 cohorts. These are 0.1282, 0.0715, and 0.0888 respectively.



(a) Attainment: benchmark (thick), varying μ_θ (thin), and data (dashed)

(b) Mean ability

Figure 10: Accounting for the data with variation in mean ability

The new set of parameters is reported in Table 5 in Appendix E, and the success of the model in matching the targeted moments is in Table 6. Figure 10 plots the evolution of educational attainment predicted by this version of the model and contrasts it with the data. It also plots the estimated path of μ_{θ_τ}. Overall, the predicted series are much closer to the data than the benchmark. The evolution of mean ability shows an improvement up to the 1948 cohort with a subsequent decline. The rise in mean learning ability for the early cohorts, calibrated to account for the sharp decline in high school dropout rates for those cohorts, contributes to generate the dramatic increase in four year college graduation rates observed in the data. The subsequent stagnation in college attainment is the product of a decline in mean ability levels. This is enough to counteract the increased incentives to attend college due to the rise in college skill prices. The model is equally successful in accounting for the evolution of the fraction of the population with some college. Notice that the model was not calibrated to match the evolution of college attainment for the 1933-1971 cohorts in any way, so its positive performance is significant.

7 Conclusions

We study the evolution of educational attainment for the cohorts born between 1932 and 1972. The benchmark model counterfactually predicts a larger rise in four-year college graduation rates for the later cohorts (post-1960) than for the earlier ones (pre-1948). The reason is that measured skill prices for four-year college graduates rose faster, relative to high school graduates, after 1980 than during the 1950's and early 1960's. An extended version of the model with variation in mean ability levels by birth cohort is, instead, successful in accounting for the dynamics of college attainment.

We conclude with some comments on our focus, our modeling choices, and paths for future research. In order to limit the scope of our analysis and to improve comparability across cohorts, our empirical analysis has focused on males. As it is well-known, the educational attainment of females displays a different pattern than the one illustrated in Figure 1. Specifically, while female four-year college graduation rates also peak around the 1950 cohort, and decline relative to this peak for the 1950–1960 cohorts, they later rebound faster and more strongly than for males. Female four-year college graduation rates are higher than their male counterparts for the post-1960 cohorts (Goldin, Katz, and Kuziemko, 2006, Figure 1). Rendall (2010) explores the hypothesis that labor demand shifts favoring brain versus brawn can jointly account for an increase in female labor force participation, a reduction in the gender wage gap, and a reversal of the gender education gap.[49]

In terms of modeling choices, we have made the considerably strong assumption that capital markets are perfect, so that schooling choices are based on present values of earnings across different alternatives, rather than, for example, parental resources. In doing so, we do not intend to deny the potential importance of borrowing constraints for higher education. Instead, we consider our modeling approach as a useful benchmark, especially since the view that the evolution of skill prices can explain educational attainment does not postulate the existence of capital market imperfections. The presence of borrowing constraints might enhance the explanatory power of tuition in quantitatively accounting for the slow growth in college attainment for the post-1960 cohorts (Lochner and Monge-Naranjo, 2012). However, it is not clear how borrowing constraints either by themselves or interacted with tuition might explain the dramatic rise in college attainment or high school graduation for the cohorts born before the late 1940's. A second modeling choice that may be relaxed in future work is to allow skill prices to evolve over time in a cohort-specific way, even if this generalization comes with the practical difficulty of empirically disentangling age, time and cohort effects. A third interesting extension, would be to consider more explicitly the extensive margin of government provision of higher education. The share of college enrollment accounted for by the public sector peaks in the early 1970's. Thereafter, it either stagnates or even declines slightly.[50] Here we have considered the role played by expenditures per student enrolled

[49] Notice that our explanation based on inter-cohort variation in average learning ability is, in principle, consistent with the different path followed by female educational attainment. It would have to be the case that either economic forces (such as a reduction in the gender wage gap) provided females with the incentives to attain more schooling, or that the change in mean learning ability played out differently for different genders.

[50] The source for this data is the National Center for Education Statistics book: "120 Years of American Education: A Statistical Portrait" (Figure 15).

on attainment, but have not incorporated the effect of the number of college slots made available by U.S. states' budget allocations.[51]

We conclude by offering a few additional thoughts on the literature and our main conclusions. First of all, there now exist a number of alternative candidate explanations for the evolution of schooling attainment in the U.S. in the last 60 years of so. We have referred to most of them in the literature review in the introduction. Keeping in mind that different authors might focus on somewhat different time periods and samples, it would be useful to begin comparing and testing the quantitative magnitude of each alternative hypothesis. In doing so we think that it would be beneficial to consider the entire spectrum of possible levels of education, instead of focusing on the choice of college conditional on high school. The coincident timing of stagnation of different levels of schooling in the U.S. suggests a common explanation. Focusing on high school, in addition to college, graduation should provide a useful test for alternative theories. Based on our model, we conclude that the slowdown in educational attainment is possibly due to a decline in the productivity of schooling investment at all levels of schooling. There are two broad sets of causes for such slowdown. The first one includes socio-economic factors that pertain to how parental inputs contribute to affect children's ability to learn, beginning from the womb. The second set of factors has to do with the institution in which a significant portion of a child's learning is thought to occur, i.e. schools. Have schools become less efficient over time in fostering accumulation of skills? These two sets of factors might obviously also coexist and interact with one another. These are difficult, but important, issues that future research should analyze.

[51]This supply-side dimension is considered by Bound and Turner (2007) in their empirical analysis of the effects of cohort size on college enrollment.

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A Proof of Proposition 1

The proof requires showing that $V_\tau^{j'}(\theta')/\sigma + \overline{\xi}^j > V_\tau^j(\theta')/\sigma + \overline{\xi}^{j'}$ for $j' \leq j$ whenever $V_\tau^{j'}(\theta)/\sigma + \overline{\xi}^j = V_\tau^j(\theta)/\sigma + \overline{\xi}^{j'}$. Suppose instead that $V_\tau^{j'}(\theta')/\sigma + \overline{\xi}^j \leq V_\tau^j(\theta')/\sigma + \overline{\xi}^{j'}$. This implies that

$$V_\tau^{j'}(\theta') - V_\tau^j(\theta') \leq \sigma\left(\overline{\xi}^{j'} - \overline{\xi}^j\right).$$

Given the expression for the indirect utility function the inequality above becomes

$$\ln\left(c_\tau^{j'}(\theta')\right) - \ln\left(c_\tau^j(\theta')\right) \leq \widehat{\sigma}\left(\overline{\xi}^{j'} - \overline{\xi}^j\right)$$

where

$$\widehat{\sigma} = \frac{\sigma}{\sum_{l=1}^{L}\beta^{l-1}}.$$

This further simplifies to:

$$c_\tau^{j'}(\theta') \leq c_\tau^j(\theta')\exp\left[\widehat{\sigma}\left(\overline{\xi}^{j'} - \overline{\xi}^j\right)\right].$$

Replace equation (3.6) so that the inequality becomes:

$$\sum_{l=S_{j'}+1}^{L} R^{-(l-1)}\left(1-\lambda_{\tau+14+l}\right) w_{\tau+14+l}^{j'} h_l^{j'}(\theta') \leq \exp\left[\widehat{\sigma}\left(\overline{\xi}^{j'} - \overline{\xi}^j\right)\right] \times \sum_{l=S_j+1}^{L} R^{-(l-1)}\left(1-\lambda_{\tau+14+l}\right) w_{\tau+14+l}^{j} h_l^{j}(\theta').$$

Replace the expression (3.2) for human capital and rewrite the inequality as:

$$\frac{h^{j'}(\theta')}{h^j(\theta')} \leq \frac{\exp\left[\widehat{\sigma}\left(\overline{\xi}^{j'} - \overline{\xi}^j\right)\right]\sum_{l=S_j+1}^{L} R^{-(l-1)}\widehat{w}_{\tau+14+l}^{j}}{\sum_{l=S_{j'}+1}^{L} R^{-(l-1)}\widehat{w}_{\tau+14+l}^{j'}} \tag{A.1}$$

where the variable $\widehat{w}_{\tau+14+l}^{j}$ collects taxes, skill prices and experience profiles:

$$\widehat{w}_{\tau+14+l}^{j} \equiv \left(1-\lambda_{\tau+14+l}\right) w_{\tau+14+l}^{j}\exp\left(\delta_1\left(l-S_j-1\right) + \delta_2\left(l-S_j-1\right)^2\right).$$

Notice that since the agent with ability θ is indifferent between j and j' it must be the case that:

$$\frac{h^{j'}(\theta)}{h^j(\theta)} = \frac{\exp\left[\widehat{\sigma}\left(\overline{\xi}^{j'} - \overline{\xi}^j\right)\right]\sum_{l=S_j+1}^{L} R^{-(l-1)}\widehat{w}_{\tau+14+l}^{j}}{\sum_{l=S_{j'}+1}^{L} R^{-(l-1)}\widehat{w}_{\tau+14+l}^{j'}}. \tag{A.2}$$

Together, equations (A.1) and (A.2) imply that:

$$\frac{h^{j'}(\theta')}{h^{j}(\theta')} \leq \frac{h^{j'}(\theta)}{h^{j}(\theta)}$$

for $\theta' > \theta$ and $j' < j$. This leads to a contradiction if the ratio $h^{j'}(\theta)/h^{j}(\theta)$ is strictly increasing in θ. We now show that this is the case. Notice that:

$$\frac{h^{j'}(\theta)}{h^{j}(\theta)} = \frac{h_{S_{j'}}(\theta)}{h_{S_j}(\theta)}$$

where $S_{j'} > S_j$ is the length of schooling in years associated with j' and j. Notice that we can write the ratio as the following product:

$$\frac{h_{S_{j'}}(\theta)}{h_{S_j}(\theta)} = \frac{h_{S_{j'}}(\theta)}{h_{S_{j'}-1}(\theta)} \frac{h_{S_{j'}-1}(\theta)}{h_{S_{j'}-2}(\theta)} \cdots \frac{h_{S_j+1}(\theta)}{h_{S_j}(\theta)}.$$

To show that the left-hand is increasing in θ, it is then enough to show that each ratio on the right-hand side is increasing in θ. Thus, we simply need to show that

$$\frac{h_{l+1}(\theta)}{h_l(\theta)}$$

is increasing in θ where $h_{l+1}(\theta)$ is given by equation (3.1). We do so by induction. First, we show this is the case for $l = 2$ and then that it holds for $h_{l+2}(\theta)/h_{l+1}(\theta)$ given that it holds for $h_{l+1}(\theta)/h_l(\theta)$. Consider first the case $l = 2$. Since

$$h_2(\theta) = \theta h_1^{\gamma} + (1-\mu)h_1,$$

it is straightforward to show that $h_2(\theta)/h_1$ is increasing in θ given that h_1 is the same for all agents. Now consider the inductive argument. Suppose that $h_{l+1}(\theta)/h_l(\theta)$ is increasing in θ, where:

$$\frac{h_{l+1}(\theta)}{h_l(\theta)} = \theta h_l(\theta)^{\gamma-1} + 1 - \mu.$$

The ratio on the left-hand-side is increasing in θ if and only if $x(\theta) \equiv \theta h_l(\theta)^{\gamma-1}$ is increasing in θ. Now consider

$$\begin{aligned}
\frac{h_{l+2}(\theta)}{h_{l+1}(\theta)} &= \theta h_{l+1}(\theta)^{\gamma-1} + 1 - \mu \\
&= \theta\left(\theta h_l(\theta)^{\gamma} + (1-\mu) h_l(\theta)\right)^{\gamma-1} + 1 - \mu \\
&= x(\theta)\left(x(\theta) + 1 - \mu\right)^{\gamma-1} + 1 - \mu.
\end{aligned}$$

To show that $h_{l+2}(\theta)/h_{l+1}(\theta)$ increases with θ, take the derivative with respect to θ, and collect terms to obtain:

$$\frac{\partial\left[h_{l+2}(\theta)/h_{l+1}(\theta)\right]}{\partial\theta} = x'(\theta)\left(x(\theta)+1-\mu\right)^{\gamma-2}\left[1-\mu+x(\theta)\gamma\right] > 0$$

where the inequality follows because $x'(\theta) > 0$ by assumption. Q.E.D.

B Proof of Proposition 2

By definition:

$$\begin{aligned}
\frac{P_\tau^{j'}(\theta)}{P_\tau^{j}(\theta)} &= \frac{\exp\left(V_\tau^{j'}(\theta)/\sigma + \overline{\xi}^{j'}\right)}{\exp\left(V_\tau^{j}(\theta)/\sigma + \overline{\xi}^{j}\right)} \\
&= \exp\left(\left(V_\tau^{j'}(\theta) - V_\tau^{j}(\theta)\right)/\sigma + \overline{\xi}^{j'} - \overline{\xi}^{j}\right).
\end{aligned}$$

Notice also that:

$$V_\tau^{j'}(\theta) - V_\tau^{j}(\theta) = \ln\left(\frac{c_\tau^{j'}(\theta)}{c_\tau^{j}(\theta)}\right)\sum_{l=1}^{L}\beta^{l-1}$$

and that the ratio of consumptions $c_\tau^{j'}(\theta)/c_\tau^{j}(\theta)$ is increasing in θ if and only if the ratio of human capitals $h^{j'}(\theta)/h^{j}(\theta)$ also is. We have already shown in the proof of Proposition 1 that $h^{j'}(\theta)/h^{j}(\theta)$ is indeed increasing in θ.

The density of ability among education levels is, by definition:

$$p_\tau(\theta|j) = \frac{P_\tau^{j}(\theta)g(\theta)}{\int_0^\infty P_\tau^{j}(\theta)dG(\theta)},$$

where $g(\theta)$ is the density of ability. To prove that $p_\tau(\theta|j')$ first-order stochastically dominates

$p_\tau(\theta|j)$ it is sufficient to show that there is a cut-off $\overline{\theta}_\tau^{jj'}$:

$$\begin{aligned} \frac{p_\tau(\theta|j)}{p_\tau(\theta|j')} &\geq 1 \text{ for } \theta \leq \overline{\theta}_\tau^{jj'} \\ \frac{p_\tau(\theta|j)}{p_\tau(\theta|j')} &< 1 \text{ for } \theta > \overline{\theta}_\tau^{jj'}. \end{aligned}$$

Notice that

$$\frac{p_\tau(\theta|j)}{p_\tau(\theta|j')} = \frac{P_\tau^j(\theta)}{P_\tau^{j'}(\theta)} \frac{\int_0^\infty P_\tau^{j'}(\theta) dG(\theta)}{\int_0^\infty P_\tau^j(\theta) dG(\theta)}.$$

This ratio is strictly decreasing in θ by the first part of this proposition. It remains to be shown that for $\theta \to 0$ the ratio is larger than 1. If that's the case, the fact that the ratio is decreasing implies that there exists a $\overline{\theta}_\tau^{jj'}$ with the desired property. Suppose then that for $\theta \to 0$ the ratio is weakly smaller than 1. This implies that as θ grows the ratio is decreasing even further, so that:

$$p_\tau(\theta|j) \leq p_\tau(\theta|j')$$

for all values of θ with at least a strict inequality for some θ. This cannot be the case since both $p_\tau(\theta|j)$ and $p_\tau(\theta|j')$ are densities and have to integrate to one. Q.E.D.

C Data

C.1 Attainment Effects of War Conflicts and GI Bills

In our modelling analysis of Section 3, we restrict attention to the cohorts born between 1932 and 1972. Notice that individuals in these cohorts were not affected by the 1944 GI Bill, as they were too young to have served during Wold War II. However, individuals in the 1932–1935 cohorts might have served in the Korea War (1950–53) and hence been affected by the Korea GI Bill of 1952 (Stanley, 2003). Moreover, the opportunity to defer the Vietnam War draft (whose open combat period spans the years 1965-73) afforded by the pursuit of a college degree might have motivated individuals born between 1940 and 1954 to enroll in college (Card and Lemieux, 2001b). It is therefore natural to assess the contribution of these events to the educational achievement of the relevant cohorts displayed in Figure 1.[52]

Stanley (2003, page 673) finds that the increase in post-secondary educational attainment attributable to the Korea GI Bill was largest for the 1921–1933 cohorts. According to his

[52]Notice that the mechanisms by which these two wars might have affected educational attainment are similar. The Korea GI Bill operated on the direct cost of attending college by subsidizing college tuition and living expenses for veterans. The possibility of deferring (and eventually avoiding) the Vietnam draft reduced the opportunity cost of attending college.

estimates, eligibility for the Korea GI Bill benefits increased college graduation rates by 5 to 6 percentage points among veterans of the Korea War. Notice that if we were to net out from the attainment data the increase in four-year college graduation attributable to the Korea GI Bill, we would have to explain an even larger increase in attainment for the 1928–1948 cohorts than is observed in the data. Card and Lemieux (2001b, Table 1B) estimate the excess college graduation rate due to draft avoidance behavior by cohort. According to their results, draft avoidance led to an increase in four-year college graduation rates by 1 percentage point for individuals in the 1941 cohort, 2.22 percentage points for individuals in the 1947 cohort (the peak effect), and 0.50 percentage points for individuals in the 1951 cohort.[53] Card and Lemieux (2001b, page 101) conclude their paper arguing that "these effects are modest relative to the overall slowdown in the rate of growth in educational attainment that occurred between cohorts born in the 1940's and those born in the 1950's." In light of these numbers, we conclude that neither the Korea GI Bill nor the Vietnam War had a significant effect on the basic facts we are set of explain. We therefore chose not to further adjust the data when calibrating the model or when interpreting the results.

C.2 Sample Selection

We work with two main samples, an attainment sample and an earnings sample. Both samples are drawn from the Current Population Survey (CPS) 1964–2010 and the U.S. 1950 and 1960 Census. They both include white males, ages 23–65. Since the Current Population Survey does not provide information on an individual's birthplace before 1994, we do not condition on U.S. born individuals.[54] In what follows we explain the difference between the two samples and the purposes for which they are used.

C.2.1 Attainment Sample

The attainment sample is used to construct Figure 1 and to calibrate the model. Since the population we study in the model refers to individuals with more than a middle-school degree, the attainment data used for calibration purposes in Section 4.1.3 are computed relative to the sample of individuals who have at least attended one year of high school. For completeness, in Figure 1 we plot the attainment data for all education categories, including middle school.

[53]The corresponding figures for some college attendance (as opposed to completion of a four-year degree) are 1.80, 4.01 and 0.90.

[54]Carneiro and Heckman (2003) and Goldin and Katz (2008) show that the slowdown in U.S. educational attainment since 1970 is not due to immigration.

The raw attainment data for the population 23–65 presents us with one caveat. The age of college graduation and attendance has changed over time, with individuals in later cohorts more likely to graduate in their late 20s than earlier cohorts. Since our model assumes that agents graduate from college at age 22, we adjust the data to be consistent with this assumption, rather than introducing flexible graduation dates in the model. As a useful by-product, our procedure also allows us to infer college attainment rates at age 23 for the 1928-1940 cohorts, for whom we have no direct observation at age 23 in the CPS.[55] We begin by computing the raw attainment rates for each education level in the population of white males, for each age and cohort. We then regress, for each educational level, the attainment rate on a full set of age and cohort dummies. Without further restrictions, we cannot separately identify all the age and cohort effects. Under the assumption that the raw attainment rate at age 23 equals the "true" one for the 1941 cohort (the first cohort we observe in the CPS at age 23), we are able to do so. The series plotted in Figure 1 represent precisely the coefficient on the age 23 dummy plus the coefficients on each of the cohort dummies.

To evaluate our adjustment procedure, Figure 11 reproduces the same age-adjusted series as in Figure 1 (solid lines), together with the raw series for attainment at age 23 (dashed lines), for those cohorts for which we have information in the CPS. The most important message is that two series display the same overall behavior. Our adjustment allows us to begin with the 1928 rather than with the 1941 cohort. In addition, notice for example how the age-adjusted series for "four-year college" is higher than the raw series after the 1960 cohort. This is because individuals in these cohorts began taking longer to finish four-year college programs. By determining a higher cohort dummy as a result of this behavior, our procedure infers a higher "true" attainment for these later cohorts.

C.2.2 Earnings Sample

The earnings sample is a subset of the attainment sample. It further restricts attention to individuals who work full-time and full-year, i.e. working at least 35 hours per week at the time of the survey, and who worked at least 40 weeks and had positive earnings in the previous calendar year. By restricting attention to workers with a strong attachment to the labor force we are able to minimize the influence of composition effects in the measurement of earnings over time. Real weekly earnings are obtained by dividing annual earnings by weeks worked last year and by deflating them using the consumer price index. In doing so for each year and skill group we eliminate from the sample workers in the top and bottom

[55] For example, we only start observing individuals from the 1928 cohort in 1963 (i.e. from the information provided in the 1964 CPS), when they are 37 years old.

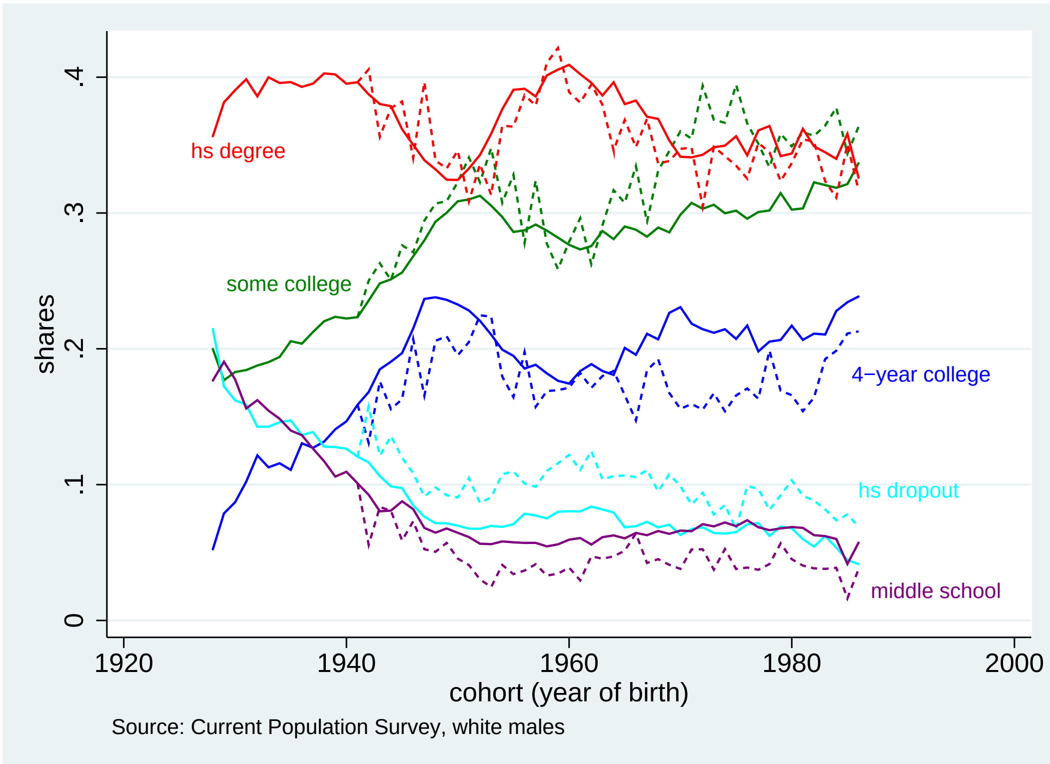

Figure 11: Educational attainment at age 23 by birth cohort: age-adjusted (solid) vs raw (dashed).

one percent of the weekly earnings distribution.

The earnings sample is used to construct Figure 2 and, further restricting attention to individuals with at least a year of high school, it is used to compute the series for skill prices in Section 4.1.1 and the moments related to education earnings premia in Section 4.1.3.

C.3 Tuition

The tuition data series we use is from the *Digest of Education Statistics* (2010, Table 345) for data after 1976 and the book *120 Years of American Education: A Statistical Portrait* (Table 33) for data prior to 1976. Both sets of data include only tuition and required student fees, and are net of room and board (since room and board is not a net cost of education). The data aggregates information from public and private institutions and tuition is in-state for public institutions. Separate data for two and four-year college programs are available only after 1976. We construct the four and two year tuition data prior to 1976 by assuming that the growth rate of each of these two series is the same as the growth rate for aggregate college tuition per student (i.e. the series that does not distinguish between two and four-year programs). Using these growth rates we extrapolate both series backward all the way to the academic year 1950-51. In order to calibrate the level of tuition we construct the present value of four-year tuition for academic year 1950-51 and divide it by the average yearly earnings of high school dropouts in 1949. The resulting ratio is approximately equal to 0.82. We target this moment in the calibration of the version of the model with tuition.

C.4 Schooling Expenditures

We concentrate on nominal current-fund expenditures per student in fall enrollment, from 1947 until 1994. This allows us to generate comparable series across time and degrees. For elementary and secondary schooling, the data comes from Table 190 of the *2010 Digest of Education Statistics* and Table 170 of the *2000 Digest of Education Statistics*. For higher education, the data on expenditures comes from Table 338 of the *2000 Digest of Education Statistics*, and the data on fall enrollment comes from Table 198 of the *2010 Digest of Education Statistics*. Separate series for two-year and four-year programs are available only starting in 1970 (aggregated between public and private institutions). Notice that for the purpose of allocating expenditures, we identify the "some college" category in the model with a two-year program. The observations prior to 1970 were imputed by the following method. We assume per student expenditures in four-year programs ($x_t^{4\text{yr}}$) relative to two-year ($x_t^{2\text{yr}}$) remained constant prior to 1970 at the 1970 level, $x_t^{4\text{yr}}/x_t^{2\text{yr}} = x_{1970}^{4\text{yr}}/x_{1970}^{2\text{yr}}$ for $t < 1970$, and then use the following identity to infer $x_t^{2\text{yr}}$ from the aggregate per student spending in higher education (x_t^{he}): $x_t^{2\text{yr}} = x_t^{\text{he}}/(e_t^{2\text{yr}} + e_t^{4\text{yr}} x_{1970}^{4\text{yr}}/x_{1970}^{2\text{yr}})$, for $t < 1970$, where $e_t^{2\text{yr}}$ and $e_t^{4\text{yr}}$ are, respectively, the share of two-year and four-year fall enrollment in the higher education aggregate. This imputation method factors in the possibility that aggregate per student expenditures might vary over time due changes in the composition of higher education enrollment, but not necessarily changes in per student expenditures in each type of program. For a small number of years, observations are missing for all variables. To generate a complete panel for nominal expenditures, we imputed them by linear interpolation. Nominal per student expenditures were then deflated by the Personal Consumption Expenditure aggregate price index for education services, which is available from Table 2.4.4. of the NIPA.

D Estimates of Experience Profile Parameters

The OLS estimates of the experience profile parameters δ_2^j are reported in the following table:

Education Level	Estimate	Standard Error
$j = 1$	-0.0009908^{**}	0.0000937
$j = 2$	-0.0008688^{**}	0.0001047
$j = 3$	-0.0006231^{**}	0.0000762
$j = 4$	-0.0006000^{**}	0.0001317

Note: ** denotes statistical significance at the 1 percent level.

Table 4: Estimates of the experience parameters δ_2^j.

Figure 12 plots the estimated experience-earnings profiles by education group, for individuals with learning ability $\theta = 1$ born in cohort $\tau = 1950$. In order to isolate the role of the experience profiles in shaping earnings, we keep skill prices constant at the level observed by these individuals at age 17. These happen to be the skill prices agents expect to face over their entire lifetime when we consider myopic expectations in Section 5.3.

Our estimates of the experience profile parameters $\{\delta_1^j\}$ and $\{\delta_2^j\}$ imply that age-earnings profiles have the typical hump-shape, independently of schooling level, and that they are steeper for higher schooling levels. The profiles for different degrees are shifted proportionally depending on type of individual under consideration. This is either due to differences in skill prices, or due to differences in human capital when finishing school $h_\tau^j(\theta)$. For individuals of type $(\theta, \tau) = (1, 1950)$ in particular, some college is dominated in terms of lifetime earnings profile relative to the remaining schooling options.

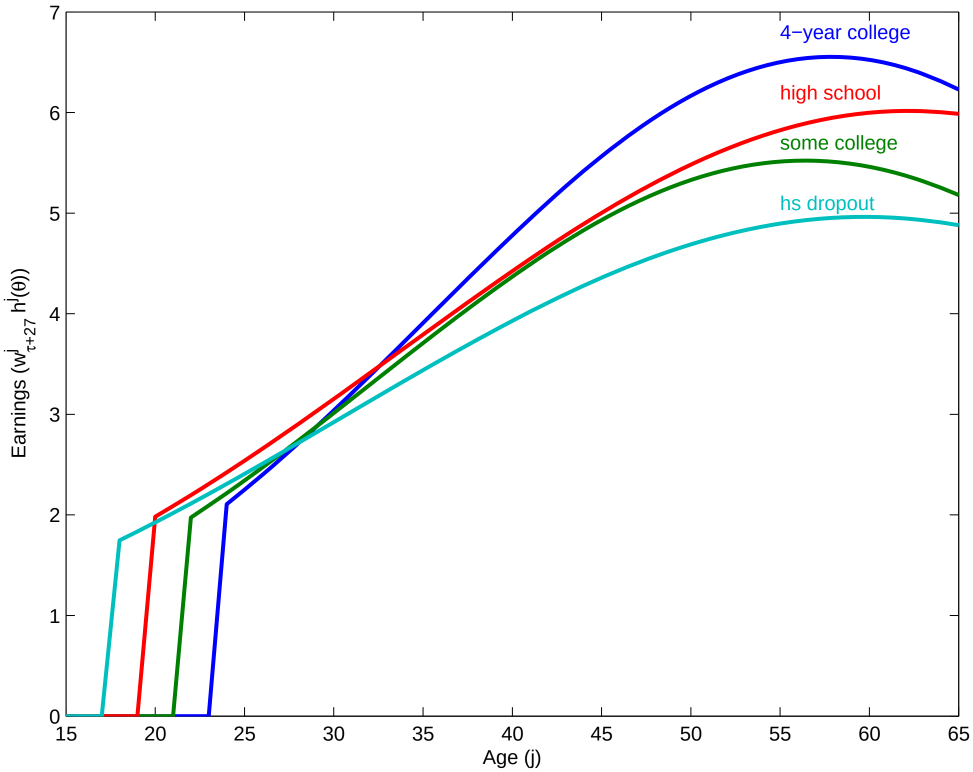

Figure 12: Lifetime earnings profile for an individual of type $(\theta, \tau) = (1, 1950)$.

E Calibration Parameters and Moment Matching

The following table presents the set of parameters corresponding to each model version considered in the paper.

Parameter	Model Version		
	Benchmark	Myopia	Changing μ_θ
σ	4.6659	4.1205	2.3470
σ_θ	0.1316	0.1329	0.1436
$\bar{\xi}^1$	-0.0320	-0.8813	-2.0958
$\bar{\xi}^2$	-0.7425	-1.3476	-1.8858
$\bar{\xi}^3$	-0.9757	-1.0202	-1.2171
w_0^1	0.0159	0.0155	0.0127
w_0^2	0.0411	0.0418	0.0393
w_0^3	0.1325	0.1341	0.1359
w_0^4	0.3827	0.3858	0.4011
δ_1^1	0.0668	0.0671	0.0594
δ_1^2	0.0585	0.0598	0.0535
δ_1^3	0.0517	0.0526	0.0479
δ_1^4	0.0494	0.0501	0.0482
μ_θ^1			-0.0029
μ_θ^2			0.0071
μ_θ^3			-0.0119
μ_θ^4			0.0004

Table 5: Calibration

The last four parameters apply to the functional form for mean ability in the version of the model presented in Section 6:

$$\mu_{\theta\tau} = \begin{cases} \exp(\mu_\theta^1(\tau-1)), & \tau \leq 9; \\ \exp(\mu_\theta^1(9-1)+\mu_\theta^2(\tau-9)), & 9 < \tau \leq 17; \\ \exp(\mu_\theta^1(9-1)+\mu_\theta^2(17-9)+\mu_\theta^3(\tau-17)), & 17 < \tau \leq 33; \\ \exp(\mu_\theta^1(9-1)+\mu_\theta^2(17-9)+\mu_\theta^3(33-17)+\mu_\theta^4(\tau-33)), & \tau > 33. \end{cases}$$

The following table summarizes the success of each model version in matching the targeted data moments.

Moments	Model version			
	Data	Benchmark	Myopia	Changing μ_θ
Educational attainment, 1932 cohort				
1. High school	0.4606	0.4605	0.4589	0.4563
2. Some college	0.2240	0.2271	0.2257	0.2236
3. Four-year college	0.1451	0.1432	0.1439	0.1446
Educational attainment, 1972 cohort				
4. High school	0.3690	0.3689	0.3709	0.3732
5. Some college	0.3263	0.3215	0.3246	0.3273
6. Four-year college	0.2308	0.2336	0.2331	0.2325
Education premiums (relative to high school), 1932 cohort				
7. High school dropout	0.9261	0.9301	0.9250	0.9180
8. Some college	1.0650	1.010	1.0214	1.0268
9. Four-year college	1.1546	1.2018	1.1925	1.1677
Education premiums (relative to high school), 1972 cohort				
10. High school dropout	0.7485	0.7476	0.7507	0.7541
11. Some college	1.1084	1.1607	1.1508	1.1446
12. Four-year college	1.5741	1.4973	1.5148	1.5583
13. Earnings in 2009 relative to 1959, four-year college (all cohorts)	1.9928	1.9838	1.9856	1.9853
14. Stddev log weekly earnings, 1932 cohort, four-year college	0.3550	0.3561	0.3558	0.3541
15. Present value of 4 year college tuition relative to earnings of high school dropout in 1949	0.8772	0.8800	0.8788	0.8817
High school dropout rate				
16. 1942 cohort	0.1282			0.1279
17. 1952 cohort	0.0715			0.0715
18. 1962 cohort	0.0888			0.0887

Table 6: Targeted Moments