

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

## Online Appendix

Rui Castro\*      Daniele Coen-Pirani†

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### A Aggregation

In this section we formally define some of the variables to which we refer in the calibration sections of the main text. The proportion of individuals in each cohort  $\tau$  choosing schooling-level  $j$  (educational attainment rate for education level  $j$ ) is defined as:

$$AR_{\tau}^j \equiv \int_{\theta} P_{\tau}^j(\theta) dG_{\tau}(\theta). \quad (\text{A.1})$$

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

$$\frac{w_t^j \bar{h}_{\tau t}^j}{w_t^{j'} \bar{h}_{\tau t}^{j'}}, \quad (\text{A.2})$$

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\*Department of Economics, Western University. Email: [rcastro7@uwo.ca](mailto:rcastro7@uwo.ca). Web: <http://economics.uwo.ca/people/faculty/castro.html>.

†Department of Economics, University of Pittsburgh. E-mail: [coen@pitt.edu](mailto:coen@pitt.edu). Web: <https://sites.google.com/site/danicpiraniweb/>.

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

$$\bar{h}_{\tau t}^j \equiv \frac{\int_{\theta} h_{\tau t-\tau}^j(\theta) P_{\tau}^j(\theta) dG_{\tau}(\theta)}{AR_{\tau}^j}. \quad (\text{A.3})$$

## B Propositions

### B.1 Proposition 1

**Proposition 1.** *Suppose no tuition,  $Z_{\tau}^j = 0$  for all  $j$ . If an individual  $i$  of cohort  $\tau$ , with ability  $\theta$  and preference vector  $\xi_i$ , 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  $\theta'$ , with  $\theta' > \theta$  and the same preference vector  $\xi_{i'} = \xi_i$ , will find it strictly optimal to choose  $j'$ .*

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

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

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

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

where

$$\hat{\sigma} = \frac{\sigma}{\sum_{a=17}^A \beta^a}.$$

This further simplifies to:

$$c_{\tau}^{j'}(\theta') \leq c_{\tau}^j(\theta') \exp \left[ \hat{\sigma} \left( \bar{\xi}^{j'} - \bar{\xi}^j \right) \right]. \quad (\text{B.1})$$

For agent  $\theta$  we have:

$$c_{\tau}^{j'}(\theta) = c_{\tau}^j(\theta) \exp \left[ \widehat{\sigma} \left( \bar{\xi}^{j'} - \bar{\xi}^j \right) \right]. \quad (\text{B.2})$$

Notice that consumption can be written as:

$$c_{\tau}^j(\theta') = \frac{h^j(\theta') \sum_{a=7+S_j}^A R^{-a} \widetilde{w}_{\tau+a}^j}{\sum_{a=17}^A R^{-a}},$$

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

$$\widetilde{w}_{\tau+a}^j \equiv (1 - \lambda) \widetilde{w}_{\tau+a}^{j'} \exp \left( \delta_1^j (a - S_j - 7) + \delta_2^j (a - S_j - 7)^2 \right),$$

and  $h^{j'}(\theta')$  denotes human capital at the end of schooling level  $j'$ . Thus:

$$\begin{aligned} c_{\tau}^{j'}(\theta') &= \left[ h^{j'}(\theta') / h^j(\theta) \right] \frac{\sum_{a=7+S_j}^A R^{-a} \widetilde{w}_{\tau+a}^j h^j(\theta)}{\sum_{a=17}^A R^{-a}} \\ &= \frac{h^{j'}(\theta')}{h^j(\theta)} c_{\tau}^j(\theta). \end{aligned}$$

Thus, equation (B.1) holds if

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

Use (B.2) to re-write as:

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

This leads to a contradiction if the ratio  $h^{j'}(\theta) / h^j(\theta)$  is strictly increasing in  $\theta$ . 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 side is increasing in  $\theta$ , it is then enough to show that each ratio on the right-hand side is increasing in  $\theta$ . Fix a cohort  $\tau$  and, without loss of generality, fix also a degree  $j$ . We simply need to show that

$$\frac{h_{a+1}(\theta)}{h_a(\theta)}$$

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

$$h_2(\theta) = \theta x_1^\varphi h_1^\gamma + (1 - \mu)h_1,$$

it is straightforward to show that  $h_2(\theta)/h_1$  is increasing in  $\theta$  given that  $h_1$  is the same for all agents. Now consider the inductive argument. Notice that

$$\frac{h_{a+1}(\theta)}{h_a(\theta)} = \theta x_a^\varphi h_a(\theta)^{\gamma-1} + 1 - \mu. \quad (\text{B.3})$$

Use the analogous expression for  $h_a(\theta)/h_{a-1}(\theta)$  to write:

$$\theta x_a^\varphi h_a(\theta)^{\gamma-1} = \left( \frac{x_a}{x_{a-1}} \right)^\varphi \frac{\frac{h_a(\theta)}{h_{a-1}(\theta)} - (1 - \mu)}{\left( \frac{h_{a-1}(\theta)}{h_a(\theta)} \right)^{\gamma-1}}.$$

Replace it in (B.3) to obtain:

$$\frac{h_{a+1}(\theta)}{h_a(\theta)} = \left( \frac{x_a}{x_{a-1}} \right)^\varphi \left\{ \left( \frac{h_a(\theta)}{h_{a-1}(\theta)} \right)^\gamma - (1 - \mu) \left( \frac{h_a(\theta)}{h_{a-1}(\theta)} \right)^{\gamma-1} \right\} + 1 - \mu.$$

Notice that, if  $h_a(\theta)/h_{a-1}(\theta)$  is increasing in  $\theta$ , so is  $h_{a+1}(\theta)/h_a(\theta)$  because  $\gamma < 1$ . Thus, the ratio  $h_{a+1}(\theta)/h_a(\theta)$  is increasing in  $\theta$  for all  $a \geq 1$ . Q.E.D.

## B.2 Proposition 2

**Proposition 2.** *Suppose no tuition,  $Z_\tau^j = 0$  for all  $j$ . 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  $j$ .*

By definition:

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

Notice also that:

$$V_\tau^{j'}(\theta) - V_\tau^j(\theta) = \ln \left( \frac{c_\tau^{j'}(\theta)}{c_\tau^j(\theta)} \right) \sum_{a=17}^A \beta^a$$

and that the ratio of consumptions  $c_\tau^{j'}(\theta) / c_\tau^j(\theta)$  is given by:

$$\frac{c_\tau^{j'}(\theta)}{c_\tau^j(\theta)} = \frac{h^{j'}(\theta)}{h^j(\theta)} \frac{\sum_{a=7+S_{j'}}^A R^{-a} \tilde{w}_{\tau+a}^{j'}}{\sum_{a=7+S_j}^A R^{-a} \tilde{w}_{\tau+a}^j}. \quad (\text{B.4})$$

The latter is increasing in  $\theta$  if the ratio of human capitals  $h^{j'}(\theta) / h^j(\theta)$  is increasing in  $\theta$ . We have already shown in the proof of Proposition 1 that  $h^{j'}(\theta) / h^j(\theta)$  is indeed increasing in  $\theta$ .

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

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

where  $g_\tau(\theta)$  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  $\bar{\theta}_\tau^{jj'}$  :

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

Notice that

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

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

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

for all values of  $\theta$  with at least a strict inequality for some  $\theta$ . 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 II in the paper, 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

World 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, 2001). It is therefore natural to assess the contribution of these events to the educational achievement of the relevant cohorts displayed in Figure 1a of the paper.<sup>1</sup>

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 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 (2001, 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.<sup>2</sup> Card and Lemieux (2001, 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 1940s and those born in the 1950s.” Angrist and Chen (2011) attempt to measure the effect of the Vietnam GI bill on education attainment exploiting randomization induced by the draft-lottery. They estimate that veteran status increase (in a causal sense) college completion by about 5 percentage points for whites (see their Table 3) in the 1948–

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<sup>1</sup>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.

<sup>2</sup>The corresponding figures for some college attendance (as opposed to completion of a four-year degree) are 1.80, 4.01 and 0.90.

1952 cohorts. Given that about 24 percent of white males in those cohorts served in Vietnam, the Vietnam war GI bill might have increased educational attainment of those cohorts by about one percentage point, a relatively small number.

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

Our sample is drawn from the March Current Population Survey (CPS) 1964–2010 and the U.S. 1950 and 1960 Censuses.

We 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.<sup>3</sup>

We focus on individuals who have attended at least one year of high school, since the population we study in the model refers to individuals with more than a middle-school degree.<sup>4</sup>

We also 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).

The sample 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

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<sup>3</sup>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.

<sup>4</sup>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.



who worked at least 40 weeks and had positive earnings in the previous calendar year. By focusing attention on 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 one percent of the weekly earnings distribution.

Regarding educational attainment, one issue is that 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. We therefore consider the highest degree that individuals report sufficiently late in life. In practice, for a given cohort and degree, we compute the average graduation rate reported between ages 30 and 40. We consider the 30-40 age average in order to obtain reliable estimates, since the number of observations from the CPS is very small once we condition on age, cohort, and degree. We stop at age 40 to prevent death rates, which are systematically associated with education, from affecting our attainment figures.

### **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 ( $x_t^{4yr}$ ) relative to two-year ( $x_t^{2yr}$ ) remained constant prior to 1970 at the 1970 level,  $x_t^{4yr}/x_t^{2yr} = x_{1970}^{4yr}/x_{1970}^{2yr}$  for  $t < 1970$ , and then use the following identity to infer  $x_t^{2yr}$  from the aggregate per student spending in higher education ( $x_t^{he}$ ):  $x_t^{2yr} = x_t^{he}/(e_t^{2yr} + e_t^{4yr} x_{1970}^{4yr}/x_{1970}^{2yr})$ , for  $t < 1970$ , where  $e_t^{2yr}$  and  $e_t^{4yr}$  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  $\delta_2^j$  are reported in Table 1. Our calibrated values for the profile parameters  $\delta_1^j$  are in Table 2 of the paper. We concentrate here on the case of static expectations.

Table 1: Estimates of the experience parameters  $\delta_2^j$ .

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.

Figure 1 plots the estimated experience-earnings profiles by education, for an individual with learning ability  $\theta = 1$  and born in cohort  $\tau = 1948$ . Consistent with our static expectations assumption, we keep skill prices constant at the level observed by individuals of this type at age 17.

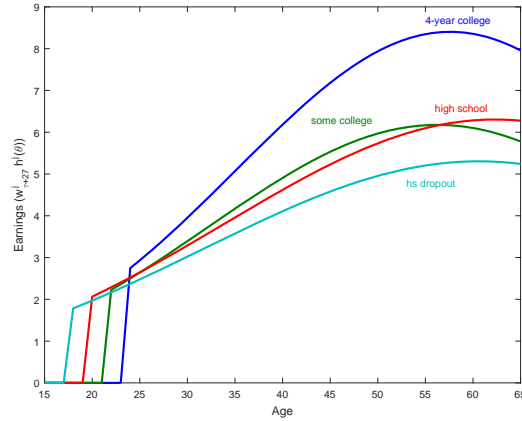


Figure 1: Lifetime earnings profile for an individual of type  $(\theta, \tau) = (1, 1948)$ .

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 the type of individual under consideration. This is either due to differences in skill prices, or due to differences in human capital when finishing school  $h_{\tau 7+s_j}^j(\theta)$ . Given the lifetime earnings profiles displayed in the figure, a large fraction of the individuals of type  $(\theta, \tau) = (1, 1948)$  end up choosing to graduate from a four-year college program.

## E Alternative Calibration

The calibrated parameters and the moment matching of the alternative calibration of our model are displayed in Tables 2 and 3.

Table 2: Alternative Calibration

Parameter	Value
$\sigma$	4.2938
$\sigma_\theta$	0.0618
$\xi^{-1}$	2.9841
$\xi^{-2}$	2.2633
$\xi^{-3}$	1.8017
$w_0^1$	0.0006
$w_0^2$	0.0012
$w_0^3$	0.0026
$w_0^4$	0.0053
$\delta_1^1$	0.0340
$\delta_1^2$	0.0308
$\delta_1^3$	0.0264
$\delta_1^4$	0.0333
$\mu_{\theta 1963}$	0.6651

Table 3: Targeted Moments, Alternative Calibration

Moments	Data	Model
<i>Educational attainment, 1932 cohort</i>		
1. High school	0.3976	0.3759
2. Some college	0.1971	0.1940
3. Four-year college	0.2479	0.2407
<i>Educational attainment, 1972 cohort</i>		
4. High school	0.3024	0.3150
5. Some college	0.2724	0.2796
6. Four-year college	0.3623	0.3765
<i>Education premiums (relative to high school), 1932 cohort</i>		
7. High school dropout	0.9261	1.0286
8. Some college	1.0650	0.9960
9. Four-year college	1.1546	1.1150
<i>Education premiums (relative to high school), 1972 cohort</i>		
10. High school dropout	0.7485	0.6468
11. Some college	1.1084	1.1615
12. Four-year college	1.5741	1.6585
13. Earnings in 2009 relative to 1959, all cohorts	1.7022	1.6780
14. Std deviation log weekly earnings, 1932 cohort	0.2513	0.2474
15. Present value of 4 year college tuition relative to earnings of high school dropout in 1949	0.8772	0.8899
<i>High-school dropout rates</i>		
16. 1935 cohort	0.1654	0.1520
17. 1940 cohort	0.1219	0.1070
18. 1945 cohort	0.0913	0.0773
19. 1950 cohort	0.0550	0.0622
20. 1955 cohort	0.0524	0.0620
21. 1960 cohort	0.0657	0.0621
22. 1965 cohort	0.0480	0.0564
23. 1970 cohort	0.0565	0.0351
Fit (avg Euclidean percentage deviation from data)		0.1180

## Appendix References

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