The Option Value of Human Capital

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Abstract

We study college enrollment and completion decisions in the presence of risk in individuals' returns to college. Although the human capital acquired through education is irreversible (i.e., it cannot be decumulated or sold off), college education comes with two inherent options: (i) college students may drop out after obtaining additional information on their post-graduation wages and (ii) college graduates may take jobs that does not require a college degree, effectively protecting themselves from the left tail of the returns-to-college distribution. These two options may dominate standard risk aversion considerations so that enrollment may in fact increase in the face of larger risk. We calibrate our model to U.S. data on education and labor market outcomes in the 1980s and show that these option values are important for explaining the ensuing trends in college enrollment and dropout rates. In particular, we decompose the relative contributions of the first and second moments of the returns-to-college distribution to the trends in education decisions and labor market outcomes.

JEL Classifications: *I24, J24, O15*
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1 Introduction

We focus on two option values to simultaneously explain college enrollment and dropouts, and the college premium from 1980 to 2005 in the U.S.. College students can dropout upon gaining more information on their post-graduation wages, while a college graduate is allowed to take a job that did not require college education to begin with. Unlike many (but not all) previous models, enrollment and completion are choices based entirely on expections over post-graduation wages (as opposed to exogenous preference shocks, college grades, or dropout shocks). The latter option introduces the notion of "underemployment" of which data we use to discipline our model.

Literature

1. College premium and the labor force: Heckman et al. (1998); Goldin and Katz (2007); Altonji et al. (2008); Carneiro and Lee (2011); Castex (2011a)
2. College enrollment and dropouts: Kane (2001); Athreya and Eberly (2010); Castex (2011b)
3. Models based on grades (college performance): Stinebrickner and Stinebrickner (2012); Stange (2012)
4. Wage variance: Manski (1993); Heathcote et al. (2010); Cunha and Heckman (2007); Guvenen (2007); Chen (2008)
5. Credit constraints: Castex (2010); Lochner and Monge-Naranjo (2011)

2 Data

Data is primarily based on the

- Integrated Public Use Microdata Series of the Current Population Survey March supplement (IPUMS CPS) and
- Employment Projections from the Bureau of Labor Statistics (EP BLS)

Degree requirement tables by occupation from the BLS are crosswalked with the CPS using occupation codes.

Enrollment, dropout, and underemployment rates

[Figure 1 here]: Enrollment and dropout rates, male

Wage premia, variance, and lifecycle effects

[Figure 2 here]: College/dropout/underemployment premia, male, ages 25-30

[Figure 3 here]: College/dropout log wage variance, ages 25-30

[Figure 4 here]: Lifecycle earnings profiles by education/job category, male, 1980 and 2005

3 Model

Suppressing individual subscripts i, we denote by z the variable that controls one's returns to college. When individuals are 19 years old, or $s = 1$, they graduate from high school and begin with a prior z_1 based on information received up to then. If they enroll in college, they receive a signal $\hat{z} = z + \epsilon$ at the end of their second year, or $s = 2$ (21 years old).

We make the following distributional assumptions.

$$
\begin{aligned}
z &\sim \mathcal{N}\left(\mu_z, \sigma_z^2\right) \\
z_1 &\sim \mathcal{N}\left(\mu_{z_1}, \sigma_{z_1}^2\right) \\
\epsilon &\sim \mathcal{N}\left(0, \sigma^2\right)
\end{aligned}
$$

All these random variables are i.i.d. across individuals. Also, for a given individual, z_1 and ϵ are mutually independent. For those in college, we can use Bayesian updating and obtain individuals' posterior distribution of z after observing the signal.

In particular, the posterior distribution of z after observing $\hat{z}$ is

$$
\begin{aligned}
z_2 = [z|z_1, \hat{z}] &\sim \mathcal{N}\left(\mu_{z_2}, \sigma_{z_2}^2\right) \\
\mu_{z_2} &\equiv \frac{\sigma^2 \mu_{z_1} + \sigma_{z_1}^2 \hat{z}}{\sigma_{z_1}^2 + \sigma^2} \\
\sigma_{z_2}^2 &\equiv \frac{\sigma_{z_1}^2 \sigma^2}{\sigma_{z_1}^2 + \sigma^2}.
\end{aligned}
$$

We use f_1, and f_2 to denote, respectively, the p.d.f. of $z_2|z_1$ and $z|z_2$.

Individual's Problem A period is two years. An individual graduates from high school at age 19, or $s = 1$, and begins with a prior on his "return to college," z_1. Based on this, he chooses whether to enroll in college or not. If he enrolls, he must pay the expenses for the first period (two years) of college, x_1. This can be written as:

$$
V_1(a, \mu_{z_1}, \sigma_{z_1}) = \max_{\text{work,school}} \left\{ V_h(a), W_2(a, \mu_{z_1}, \sigma_{z_1}) \right\},
$$

where

$$
\begin{aligned}
V_h(a) &= \int V(a, s=1, w) g_h(w|s=1) dw \\
W_2(a, \mu_{z_1}, \sigma_{z_1}) &= \max_{a'} \left\{ u((1+r)a - a' - x_1) + \beta \int V_2(a', \mu_{z_2}, \sigma_{z_2}) f_1(z_2) dz_2 \right\}.
\end{aligned}
$$

If he foregoes enrollment and begins to work, he draws a lifetime present discounted value (PDV) of wages, y, from the high school wage distribution g_h, which is conditional on s. We will write out $V(a, s, w)$ later.

If he enrolls in college, he receives the signal $\hat{z}$ after one period (at $s = 2$). Based on this, he decides whether to drop out or to complete his college education. If he completes, he pays the expenses for the second period of college, x_2.

$$V_2(a, \mu_{z_2}, \sigma_{z_2}) = \max_{\text{work,school}} \left\{ \int V_d(a, z) df_2(z), W_3(a, \mu_{z_2}, \sigma_{z_2}) \right\},$$

where

$$\begin{aligned} V_d(a, z) &= \int V(a, s = 2, w) g_d(w|z) dw \\ W_3(a, \mu_{z_2}, \sigma_{z_2}) &= \max_{a'} \left\{ u((1 + r)a - a' - x_2) + \beta \int V_c(a', z) f_2(z) dz \right\}. \end{aligned}$$

His returns are not revealed unless he drops out. If he does, z is immediately revealed, and he draws a lifetime PDV of wages y from the dropout wage distribution g_d, which depends on z.[1]

Upon graduation, his z is revealed, and his value function is

$$V_c(a, z) = \int V(a, s = 3, w) g_c(w|z) dw.$$

When an individual starts working for the first time, be it after high school, two years in college or four years in college ($s \in \{1, 2, 3\}$), he draws a lifetime PDV of wages w from a given distribution. For simplicity, we will assume that there is no uncertainty once w is known. We that an individual works until period $R = 23$ and lives until period $T = 29$. He can borrow and save at a given interest rate, with the constraint that $a_T \geq 0$. Given the (two year) interest rate r and the discount factor β, we can derive the continuation utility of a worker who starts working at age s with lifetime PDF of wages w and financial wealth a, which is $V(a, s, w)$.

The budget constraint at age s is:

$$\sum_{j=s}^{T} \frac{c_j}{(1 + r)^{j-s}} = w + (1 + r)a,$$

and assuming CRRA preferences

$$u(c) = (1 - \beta) \frac{c^{1-\gamma}}{1 - \gamma}$$

the Euler equation would dictate that

$$\begin{aligned} u'(c_j) &= \beta(1 + r) u'(c_{j+1}) \\ c_{j+1} &= c_j \left[\beta(1 + r)\right]^{1/\gamma} \end{aligned}$$

[1] Should add reference here.

so we know the entire consumption profile by solving for c_s:

$$c_s \sum_{j=s}^{T} \left[\beta^{\frac{1}{\gamma}}(1+r)^{\frac{1}{\gamma}-1}\right]^{j-s} = w + (1+r)a$$
$$c_s = \frac{w+(1+r)a}{\kappa_c(s)}$$

where

$$\kappa_c(s) = \frac{1-\left[\beta^{\frac{1}{\gamma}}(1+r)^{\frac{1}{\gamma}-1}\right]^{T-s+1}}{1-\beta^{\frac{1}{\gamma}}(1+r)^{\frac{1}{\gamma}-1}}.$$

Then the lifetime utility starting at age s is

$$\begin{aligned} V(a,s,w) &= (1-\beta)\sum_{j=s}^{T}\beta^{j-s}\frac{c_j^{1-\gamma}}{1-\gamma} \\ &= \frac{1-\beta}{1-\gamma}\left[\frac{y+(1+r)a}{\kappa_c}\right]^{1-\gamma}\sum_{j=s}^{T}\left[\beta^{\frac{1}{\gamma}}(1+r)^{\frac{1}{\gamma}-1}\right]^{j-s} \\ &= \frac{1-\beta}{1-\gamma}\kappa_c(s)^{\gamma}\left[w+(1+r)a\right]^{1-\gamma}. \end{aligned}$$

We further assume that the worker retires at the age of 65, i.e. works until period $R = 23$ and lives until age 76, or period $T = 29$. He can borrow and save at a given interest rate, with the constraint that $a_T \geq 0$.

4 Calibration

Parametrizing the returns distribution and prior For now we assume that agents can have biased priors. We measure the bias of the mean of z_1 as the number of standard deviations, b, from the true mean, i.e.

$$\mu_{z_1} = \mu_z + b\sqrt{\sigma_z^2}.$$

and further assume that all agents have identical priors. However, we assume the variance of their priors are drawn from an Inverse-Gamma distribution

$$\sigma_{z_1}^2 \sim IG(k,\theta)$$

where k is the shape parameter. The scale parameter θ is chosen so that the mean of the IG distribution is equal to the population variance σ_z^2:

$$\theta = \sigma_z^2 \cdot (k-1)$$

Parametrizing wage distributions We make the following assumptions on the wage distributions:

1. Those who do not go to college draw only once from the high school wage distribution $g_{hs}(w_h)$. Note that one's z is irrelevant in this case.
2. Dropouts and college graduates make two wage draws, one from $g_h(\cdot|s)$ for $s = 2$ and 3, respectively, and another for jobs that require some education. We will denote these second draws for dropouts and graduates as ϖ_d and ϖ_c, respectively, which follow the distributions $g_D(\varpi_d)$ and $g_C(\varpi_c)$.
3. Dropout wages are defined as $w_d = m_d \exp(z)\varpi_d$, and college job wages as $w_c = \exp(z)\varpi_c$, where $m_d > 0$. If $m_d < 1$, 2 years of college gives the individual only partial returns.

Let $g_c(w|z)$ denote the distribution of $\max\{w_h, w_c\}$. If $G_c(w|z)$ is the c.d.f. of $g_c(w|z)$,

$$G_c(w|z) = Pr\left\{\varpi_c \le w/\exp(z) \text{ and } w_h \le w\right\},$$

where ϖ_c follows $g_C(\varpi_c)$ and w_h follows $g_h(w|s = 3)$. With independence between the two random variables,

$$G_c(w|z) = \int_0^{w/\exp(z)} g_C(\varpi_c)d\varpi_c \times \int_0^w g_h(w_h|s = 3)dw_h,$$

which is the wage distribution faced by college graduates. G_d is similarly defined. If we further assume the distributions of $(w_{hs}, \varpi_d, \varpi_c)$ are lognormal,

$$\begin{aligned}
\log w_{h_s} &\sim \mathcal{N}(\mu_{h_s}, \sigma^2_{h_s}) \\
\log \varpi_d &\sim \mathcal{N}(\mu_{h_2}, \sigma^2_d) \\
\log \varpi_c &\sim \mathcal{N}(\mu_{h_3}, \sigma^2_c)
\end{aligned}$$

so that (w_d, w_c) are also lognormal with

$$\begin{aligned}
\log m_d + z + \log \varpi_d &\sim \mathcal{N}(\mu_d, \sigma^2_d) \\
z + \log \varpi_c &\sim \mathcal{N}(\mu_c, \sigma^2_c)
\end{aligned}$$

where

$$\begin{aligned}
\mu_d &= \log m_d + \mu_z + \mu_{h_2} \\
\mu_c &= \mu_z + \mu_{h_3}
\end{aligned}$$

the max distribution can be written out explicitly using the formula for the maximum of two independent Gaussian random variables:

$$\hat{g}(\log w|z) = h_1(\log w) + h_2(\log w),$$

where

$$\begin{aligned}
h_1(x) &= \frac{1}{\sigma_h} \cdot \phi\left(\frac{x - \mu_{h_3}}{\sigma_{h_3}}\right) \cdot \Phi\left(\frac{x - \mu_c}{\sigma_c}\right) \\
h_2(x) &= \frac{1}{\sigma_c} \cdot \phi\left(\frac{x - \mu_c}{\sigma_c}\right) \cdot \Phi\left(\frac{x - \mu_{h_3}}{\sigma_{h_3}}\right),
\end{aligned}$$

and ϕ and Φ are the pdf and cdf of the standard normal distribution. So we can write

$$\begin{aligned}\hat{g}_c(\log w|z) =& \frac{1}{\sigma_{h_3}} \cdot \phi\left(\frac{\log w - \mu_{h_3}}{\sigma_{h_3}}\right) \cdot \Phi\left(\frac{\log w - \mu_c}{\sigma_c}\right) \\ &+ \frac{1}{\sigma_c} \cdot \phi\left(\frac{\log w - \mu_c}{\sigma_c}\right) \cdot \Phi\left(\frac{\log w - \mu_{h_3}}{\sigma_{h_3}}\right)\end{aligned}$$

and similarly for $\hat{g}_d(\log w|z)$.

Fixed parameters

1. $\beta = 0.96^2, \gamma = 2, r = (1.04)^2 - 1$.
2. Biennial present discounted sum of average high school wages from ages 19-20, $\tilde{w}_{h1} = 1$. (only for partial eqm)
3. High school logwage variance: while the variance should be for lifetime PDV's, since we will use earnings profiles from repeated cross section data we assume

   $$\sigma_h^2 = \mathbb{V}\left[\log \tilde{w}_{h_1}\right].$$

4. College costs (x_1, x_2): from data. The average annual cost of college is half the mean high school earnings,[2] and we take the present discounted sum of biennial college costs.

Targets and calibrated values When taking the model to the data, we first consider lifecycle effects as following. First, it is convenient to define the variable q such that

$$q = \begin{cases} h & \text{if high school graduate} \\ d & \text{if dropout} \\ c^c & \text{if college graduate with college job} \\ c^u & \text{if college graduate with high school job} \end{cases}$$

1. As in the model, normalize all wages in the data by the biennial present discounted sum of average high school wages from ages 19-20. Call these biennial wages $\{\tilde{w}_{q_s}\}_{s=1}^T$. Note that despite the retirement age $R = 23$, we add up to $T = 29$ to include post-retirement earnings, pensions and social security benefits.
2. Construct the mean lifecycle earnings profile of high school graduates and obtain e_{hs} such that

   $$e_{h_s} = \sum_{j=s}^{29} \frac{\tilde{w}_{h_j}}{(1+r)^{j-s}}$$

   for $s = 1, 2, 3$. Similarly, obtain (e_d, e_{c^c}, e_{c^u}) s.t.

   $$e_d = \sum_{j=2}^{29} \frac{w_{d_j}}{(1+r)^{j-2}}$$

[2] Need citation here

$$e_{c^c} = \sum_{j=3}^{29} \frac{w_{c^c_j}}{(1+r)^{j-3}}$$
$$e_{c^u} = \sum_{j=3}^{29} \frac{w_{c^u_j}}{(1+r)^{j-3}}.$$

This implies that

$$\mu_{h_s} - \frac{\sigma_h^2}{2} = \log e_{h_s}.$$

3. Denote the distribution over individuals' ex post wages and decisions $\Psi(w, q)$, and let

$$M_q = \int \Psi(dw, q)$$
$$W_q = \int w\Psi(dw, q)/M_q$$
$$V_q = \int (w - W_q)^2 \Psi(dw, q)/M_q$$

i.e. M_q is the model implied mass of individuals for each category q, where we are normalizing $\sum_q M_q = 1$, and the model implied mean and variance of PDV of lifetime wages for each q.

Using these constructed values, we calibrate the following parameters to the following targets:

1. b: enrollment rate, $1 - M_h$
2. $\mu_z = m_z(\mu_h - \frac{\sigma_h^2}{2})$: college premium for 23-24 year olds, $\frac{M_{c^c} W_{c^c}/e_{c^c} + M_{c^u} W_{c^u}/e_{c^u}}{M_{c^c} + M_{c^u}} \Big/ W_h/e_{h_3}$
3. $\sigma_z^2 = v_z \sigma_h^2$: college logwage variance, 23-24 year olds, $\frac{M_{c^c} V_{c^c}/e_{c^c}^2 + M_{c^u} V_{c^u}/e_{c^u}^2}{M_{c^c} + M_{c^u}}$
4. $\sigma^2 = v\sigma_h^2$: dropout rate $\frac{M_d}{1 - M_h}$
5. m_d: dropout premium for 21-22 year olds, $\frac{W_d/e_d}{W_h/e_{h_2}}$
6. $\sigma_d^2 = v_d \sigma_h^2$: dropout logwage variance, 21-22 year olds, V_d/e_d^2
7. $\sigma_c^2 = v_c \sigma_h^2$: Underemployment rate $\frac{M_{c^u}}{M_{c^c} + M_{c^u}}$
8. k: Underemployment premium, 23-24 year olds, $\frac{W_{c^u}/e_{c^u}}{W_h/e_{h_3}}$

5 Results

Decomposition of the change in premia Given the set of parameters that give us the best fit to 1980, we conduct the following experiments:

b	m_z	v_z	v^2	m_d	v_d	v_c	k

Table 1: Benchmark parameter values

1. What happens when without the option value?
   (a) Without dropout choice (i.e. no signal)
   (b) Without "call" option value
   (c) Without both
2. How much can we match 2005 moments by varying (μ_z, σ_c)?

Comparison to models without option value(s) If we recalibrate the model to 1980 without option values, how much can we match 2005 moments?

1. Without dropout choice (i.e. no signal)
2. Without "call" option value
3. Without both

Moments	1980				
	Data	Model	No dropouts	No option value	Neither
Enrollment	**50.68**				
College premium					
Log college wage variance					
Dropout rate	**41.41**				
Dropout premium					
Log dropout wage variance					
Underemployment	**29.79**				
Underemployment premium					

Table 2: Data, Model, Mechanism

Moments	1980				2005	
	Data	Model	$m_z =$	$v_c =$	Model	**Data**
Enrollment	**50.68**					
College premium						
Log college wage variance						
Dropout rate	**41.41**					
Dropout premium						
Log dropout wage variance						
Underemployment	**29.79**					
Underemployment premium						

Table 3: Matching 1980 and 2005 U.S.

Parameters	b	m_z	v_z	v_c	k

Moments	1980				2005	
	Data	No dropouts	$m_z =$	$v_c =$	No dropouts	**Data**
Enrollment	**50.68**					
College premium						
Log college wage variance						
Underemployment	**29.79**					
Underemployment premium						

Table 4: Recalibration without dropouts

Parameters	b	m_z	v_z	v^2	m_d	v_d	v_c	k

Moments	1980				2005	
	Data	No u.e.	$m_z =$	$v_c =$	No u.e.	**Data**
Enrollment	**50.68**					
College premium						
Log college wage variance						
Dropout rate	**41.41**					
Dropout premium						
Log dropout wage variance						

Table 5: Recalibration without underemployment

Parameters	b	m_z	v_z	v_c	k

Moments	1980				2005	
	Data	No options	$m_z =$	$v_c =$	No options	**Data**
Enrollment	**50.68**					
College premium						
Log college wage variance						
Dropout rate	**41.41**					
Dropout premium						
Log dropout wage variance						

Table 6: Recalibration without options

6 Conclusion

TBD.

A Appendix

Numerical Algorithm

1. **Grids** Fixed grids for (a, z). All interpolations will be linear. Let n_a denote the size of the grid for a and n_z the size of the grids for the prior, posterior, and true returns.

2. **Quadratures and terminal values** We set k-dimensional Gaussian-Hermite quadratures for wages $(w_h, \varpi_d, \varpi_c)$ and returns (z, μ_{z_2}). Compute $V(a, s, w)$ and its first derivative w.r.t. a for all values of a, then $V_h(a), V_d(a, z), V_c(a, z)$ and their derivatives w.r.t. a by summing over the w-quadratures. Compute the dropout option by summing over the μ_{z_2} quadrature. This gives us all the terminal values and their derivatives.

3. **Backward Induction Stage**

   (a) *Policy Functions for* V_2 Given the derivative of V_c, derive the savings policy a^* for the "school" option for each value of $(a, \mu_{z_2}, \sigma^2_{z_2})$ on the $n_a \times n_z$-grid, while using the quadrature over the posterior for z and interpolation to compute expectations. Once done, use the policy function to compute the value of the "school" option and the envelope theorm to compute $\partial V_2(a, \mu_{z_2}, \sigma_{z_2})/\partial a$. Compare with the "work" option to derive the binary policy function for "work" or "school."

   (b) *Policy Functions for* V_1 Given the derivative of V_2, derive the savings policy a^* for the "school" option for each value of $(a, \mu_{z_1}, \sigma^2_{z_1})$ on the $n_a \times n_z$-grid, while using the quadrature over the prior for z and interpolation . Once done, use the policy function to compute the value of the "school" option. Compare with the "work" option to derive the binary policy function $ws \in \{0, 1\}$ for $0 =$work, $1 =$school.

4. **Aggregation Stage**

   (a) Begin by linearly approximating a $s = 1$ quad-variate distribution over $(a, \mu_{z_1}, \sigma_{z_1}, z)$. Although the individuals don't know z, we need to know them as the modeller to compute probabilities.

   (b) *Enroll?* Compute decisions on each point of the approximated distribution, aggregate their decisions to compute the mass of individuals who don't enroll. For the rest, compute the masses that fall on an approximated $s = 2$ quad-variate distribution over $(a, \mu_{z_2}, \sigma_{z_1}, z)$.

   (c) *Dropout?* Compute decisions on each point of the approximated distribution, aggregate their decisions to compute the mass of individuals who dropout. For the rest, compute the masses that fall on an approximated $s = 3$ bivariate distribution over (a, z).

   (d) *Underemployed?* For each z and high school wage w_h, compute the mass of individuals who draw a lower college wage (low ϖ_c).

5. Around all this, calibrate $(b, m_z, s_z, s, m_d, s_d, s_c, k)$ to match the targets (using a downhill simplex method).

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