College Education and Income Contingent Loans in Equilibrium

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Abstract

We investigate the welfare implications of income-contingent loans (ICLs) used for financing college education in the presence of endogenous dropout risk. While providing insurance through ICLs increases college enrollment, it also generates a moral hazard cost of lowering educational effort and labor hours. We evaluate this insurance-incentives trade-off in a heterogeneous agent OLG life-cycle model calibrated to the US. We show that ICLs significantly increase welfare, the social cost of moral hazard is mild, the endogeneity of skill premium significantly reduces effectiveness of ICLs and that the non-linear repayment schedule is essential to delivering high welfare gains.

Keywords: Human Capital, Endogenous Skill Premium, Income Driven Repayments

JEL Codes: E24, I22, H81

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1 Introduction

Many policy makers view student loan programs as tools increasing equality of opportunity for students from disadvantaged backgrounds. As of today, these programs constitute arguably the most important mean of financing higher education in the US, with the level of outstanding student debt in 2020 reaching $1.7 trillion (making it the second largest debt category after mortgages). Importantly, however, these costly investments into higher education are risky as almost half of college enrollees drop out before earning a bachelor's degree. Furthermore, regardless of education outcomes, people may end up underemployed, finding it difficult to repay their student debt under standard loan programs characterized by fixed repayment amounts.

For these reasons, experts in many countries have argued for provision of income-contingent loan (ICL) programs, under which repayments increase in the current labor income.[1] In the US, the first major ICL program ("Income-Based Repayment") was enacted by the College Cost Reduction and Access Act of 2007 and has been made available since July 2009.[2] Since then, two other programs were added ("Pay as You Earn" introduced in 2012 and "Revised Pay as You Earn" introduced in 2015). As a consequence, between 2010 and 2021, the share of borrowers using ICL programs increased from 9.5% to 34%, with the total balance of loans in these programs going up from 12% to 47%.[3] Another evidence of a significant interest in this policy was the inclusion of an ICL reform proposal in Joe Biden's presidential campaign program.

In this paper, we evaluate the impact of the ICL reform in the US using a macroeconomic environment with moral hazard and uninsurable college dropout and labor productivity risks. In particular, we construct a rich life-cycle overlapping generations heterogeneous agents economy, with an endogenous skill premium (defined as the ratio of mean labor income of college graduates to mean labor income of high school graduates) and other general equilibrium effects working through prices, incomplete markets and intergenerational linkages. Newborns receive endogenous inter-vivo transfers from their parents and decide about pursuing risky college education. After leaving college, they repay their student debt, accumulate savings and make labor supply decisions in the presence of the idiosyncratic labor productivity shocks. As a final component, there is a government administering a progressive tax system, pensions, and college aid programs.

[1] The idea of income-contingent student loans has been arguably first discussed by [Friedman, 1955].

[2] The first ICL program "Income-Contingent Repayment" was introduced in the US in 1994, but was used by few college enrollees. [Shireman, 2017] discusses the history of ICLs in the US.

[3] The numbers for 2010 come from [CBO, 2020], and the ones for 2021 from the U.S. DoE data available under: https://studentaid.gov/data-center/student/portfolio.

Motivated by the empirical literature showing that students' educational effort responds to financial incentives,[4] we explicitly endogenize students' educational effort and labor supply decisions generating the trade-off between insurance and incentives. Importantly, since labor productivity is subject to idiosyncratic shocks and attending college is associated with the uninsurable dropout shock, the risk associated with rigid debt repayments implies that the enrollment of risk-averse agents is inefficiently low. While ICLs stimulate enrollment by providing insurance against this risk, they may also diminish the economic incentives for exerting educational effort or supplying labor after having left college. In Appendix A, we develop a simple two-period model of college education with the dropout risk and moral hazard, and formally characterize this incentives-insurance trade-off associated with ICLs.

We carefully calibrate our quantitative economy to match the enrollment and graduation patterns, the properties of labor markets and the tax system in the US in the year 2006, right before the introduction of the College Cost Reduction and Access Act of 2007. First, we set a number of parameters based on the institutional setup in the US and external evidence in the literature. Then, we use the Panel Study of Income Dynamics (PSID) and the National Longitudinal Surveys (NLSY) to estimate labor productivity process over the life-time of each education group. Similarly, we use NLSY to estimate the intergenerational ability transmission. In order to estimate remaining parameters of the model, we use the simulated method of moments combined with data from the Current Population Survey (CPS), NLSY97 and further evidence in the literature. Validating our calibration strategy, we show that the model's estimation fits both the targeted and non-targeted moments in the data well. In particular, in terms of the key elasticities driving education margins, we show that our estimated model matches well not only the enrollment and graduation profiles along the income and ability distributions, but also the amount of time devoted to studying and the responses of enrollment and graduation rates to expansions in financial aid.

As the main policy experiment, we introduce ICLs in a way mimicking the current institutional setup in the US, where borrowers repay a constant share of their current labor income earned in excess of the poverty threshold, up to a certain repayment limit and with any outstanding debt being forgiven 20 years after leaving college. We find that ICLs substantially reduce the loan repayment risk stemming from the dropout and idiosyncratic labor productivity shocks. As such, the reform triggers a 3.3 p.p. increase in the enrollment rate and a 0.8 p.p. increase in the share of graduates. These changes translate into a significant welfare improvement equivalent to a permanent increase of 0.82% in consumption on average. Importantly, we find that ICLs are associated with a rather mild incentives-insurance

[4]See papers by [Singell, 2004], [Scott-Clayton, 2011], [Stange, 2012], [Gunnes et al., 2013], [Adamopoulou and Tanzi, 2017], [Barrow and Rouse, 2018], [Beneito et al., 2018].

trade-off: the overall welfare cost of moral hazard both in college and labor markets is equivalent to around 20% of the reform's welfare gain. Intuitively, the adverse effects generated by ICLs are minor when compared to the expected benefits associated with graduating from college. As such, educational effort drops only by 3%. In terms of its general equilibrium consequences, the reform leads to a 4% reduction in the skill premium. Since the latter effect indirectly (and somewhat similarly to ICLs) improves insurance against the dropout risk and provides redistribution, it excessively lowers incentives for graduation and so significantly reduces the effectiveness of the reform (equivalent to 40% of welfare gains triggered by it). In terms of its fiscal impact, we find that although the reform is not self-financing, it requires only a small 1% increase in the labor income tax rate.

Finally, we move on to a comparative statics exercise, where we vary the degree of insurance and debt forgiveness embedded in ICLs. Interestingly, we find that a high enough level of the poverty threshold is essential to delivering high welfare gains as it improves the targeting of ICLs' benefits to individuals who need it more on average. Similarly, we show that lowering the upper repayment limit may be also welfare improving as it protects the most productive individuals from excessive repayments, and thus increases incentives for pursuing higher education. As such, we show that these features are essential to ensuring high effectiveness of ICLs. Moreover, these results speak directly to the very recent policy debate in the US and show that the expansion in generosity of the ICL system proposed in Joe Biden's presidential campaign may indeed improve the social welfare.

Literature review. The theoretical rationale for ICLs was laid out in [Gary-Bobo and Trannoy, 2015] and [Findeisen and Sachs, 2016], who studied different environments with human capital accumulation and moral hazard. They showed that the second best allocation can be implemented using an integrated tax and student loan system with income-contingent repayment rates. Furthermore, [Lochner and Monge-Naranjo, 2016] develop a simple human capital model used to discuss optimal student loan policy recommendations. They argue that optimally designed student loans should be balanced in aggregate and provide both the insurance against the dropout risk and the right incentives for providing educational effort. Our paper quantifies the welfare effects of ICLs in the US and shows that the moral hazard triggered by the policy is of a mild magnitude. A similar insurance-incentives trade-off has been studied in partial equilibrium by [Fan et al., 2021] focusing on the Expected Financial Contribution component introducing means-testing into the educational aid policy in the US. We complement their work by instead focusing on ICLs and analyzing the importance of general equilibrium effects.

Borrowing constraints have been centerpiece of the economics of education literature for long time. [Lochner and Monge-Naranjo, 2012] review it and conclude that in recent years credit constraints have become an important determinant of educational outcomes among the youth. [Johnson, 2013] showed that even if borrowing constraints were not binding, people may still choose not to borrow more due to the uncertainties over successful graduation and labor market opportunities. In this paper, we show that the insurance-component embedded in ICLs addresses this issue and so can lead to a significant increase in borrowing and educational attainment.

Regarding the quantitative evaluation of ICLs in the US, [Ji, 2020] finds that repayment flexibility provided by ICLs improves welfare by allowing college graduates to find better jobs. Similarly, [Folch and Mazzone, 2020] show that more indebted individuals underinvest in human capital in order to make earlier house purchases, and that ICLs can alleviate this trade-off. Furthermore, [Ionescu, 2009] evaluates the US student loan system through the lens of a (one generation) life-cycle economy with loan subsidies and risky repayment rates. She uses it to study the determinants of college enrollment and the impact of the 1986 student loan consolidation program and the 1992 relaxation of eligibility requirements reform, without analyzing the policy of ICLs. [Ionescu, 2011] considers a one-shot life-cycle economy with heterogeneous agents without moral hazard and exogenously given wage rates in order to study welfare consequences of different policies for discharging or reorganizing student debt (including ICLs). Using a two-period model of education with exogenous wage distributions, [Chatterjee and Ionescu, 2012] find that the optimal student loan policy is to provide full loan forgiveness to students that drop out of college. Furthermore, [Garriga and Keightley, 2007], [Hanushek et al., 2014], [Matsuda, 2020] and [Vardishvili, 2020] study dynamic OLG economies with human capital accumulation and financial constraints. These papers evaluate the economic impact of various college aid interventions on inequality, efficiency and college access. With respect to these papers, our quantitative model is (to the best of our knowledge) the first life-cycle framework cast in OLG setting allowing for analyzing ICLs in the presence of the incentives-insurance trade-off implied by endogenous educational effort and labor supply, and general equilibrium effects working through the endogenous skill premium.

Finally, there is a broader literature studying tax and subsidy policies in relation to education and its impact on earnings inequalities, see e.g. [Abbott et al., 2019], [Benabou, 2002], [Bovenberg and Jacobs, 2005], [Hanushek et al., 2003], [Heathcote et al., 2017], [Krueger and Ludwig, 2013] and [Krueger and Ludwig, 2016]. Most of these papers allow for general equilibrium effects of government policies on relative factor prices. We complement this literature with a quantitative evaluation of ICLs and their general equilibrium interaction with the skill premium.

Structure. This paper is organized as follows. In the next section, we outline our quantitative model, with a detailed description of its calibration strategy in Section 3. The

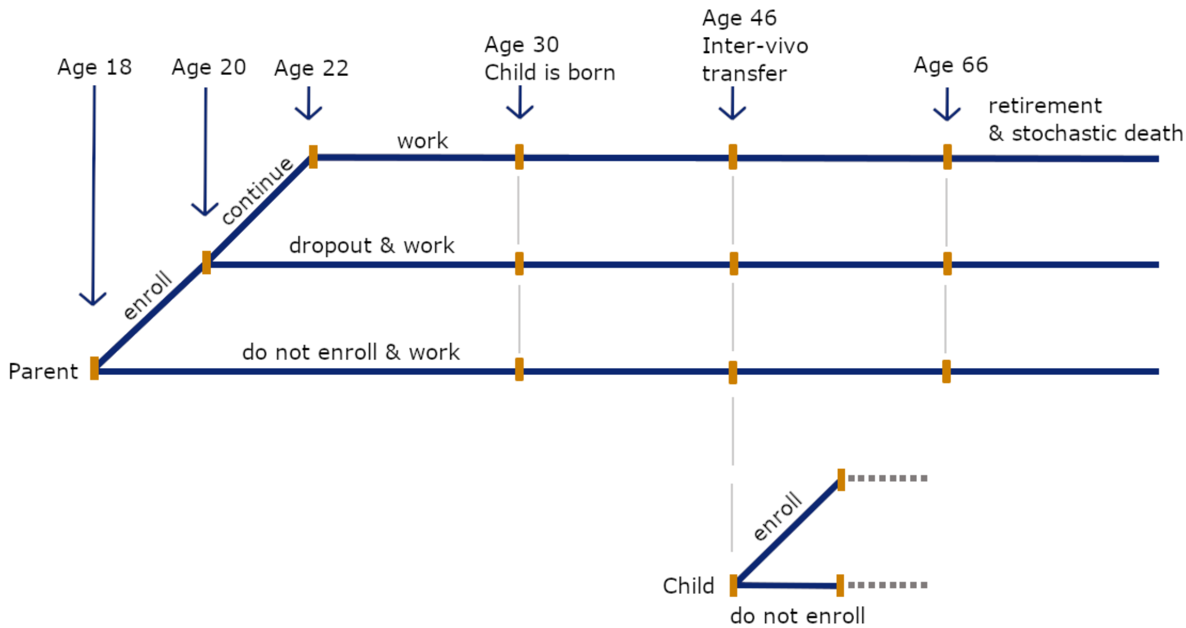

Figure 1: Timeline of events in the economy

results of the quantitative analysis are presented in Section 4. Section 5 concludes.

2 Model Economy

The economy is populated with a continuum of overlapping generations facing educational, saving and labor supply decisions along their life-cycle. Newborns face a college enrollment decision, which is associated with a dropout risk. Additionally, those who enroll make a decision on how much of educational effort to exert in order to decrease the probability of dropping out. As adults, workers have their offspring and decide about the size of inter-vivo transfers. Figure 1 summarizes the life-cycle of agents.

Moreover, there is a government administering programs of loans and subsidies for college education, progressive redistribution system and collecting tax for these purposes. All decisions are interlinked through general equilibrium effects. The skill premium in the economy is endogenized through imperfect substitution between skilled and unskilled labor, the interest rate is pinned down through endogenous capital accumulation, and the distortionary labor income tax rate is adjusted so that the government budget is balanced in every period.

Whenever possible, we discuss the parameter values chosen along the model's description. Calibration strategy regarding remaining parameters is outlined in Section 3. Because we focus on a stationary equilibrium in which the cross-sectional allocation within each cohort is invariant and prices are constant, we do not include time subscripts in the descriptions.

2.1 Demography

Time is discrete. The economy is populated by J concurrently living generations, where each generation is a unit measure of agents of age $j \in \{1, 2, \ldots, J\}$. Workers in the economy are characterized by one of the three education types e: high school graduates ($e = HS$), college dropouts ($e = CD$) and college graduates ($e = CG$).

Each agent has one offspring, which becomes independent after leaving high school (which we do not model explicitly) at age $j = 1$ (biological age 18). At that point, the offspring make a one-off decision about enrolling into college. Since we assume that one period in the model equals 2 years, college education takes 2 periods, as is usually the case in the US. Moreover, college education is risky so that students may end up as dropouts after the first period of education.

From age 20 onward ($j \geq 2$) - if an agent is a dropout; and 22 onward ($j \geq 3$) - if an agent is a graduate, they face usual life cycle decision problems. At the beginning of age $j_f = 7$ (biological age 30), they give birth to children (who become 2 years old by the end of that period) and at age $j_b = 15$ (biological age 46), agents decide about the size of wealth transfers to their children who then become independent. Everyone retires at age $j_r = 25$ (biological age 66), and lives up to the maximum age of $J = 41$ (biological age 98). While individuals survive to the next period with probability $\zeta_j = 1$ for $j \in [0, j_r - 1]$, we estimate the survival rates for all the ages between j_r and $J - 1$ from the US Life Tables 2000.

2.2 Preferences

Newborns of age $j = 1$ maximize their expected life-time utility evaluated according to:

$$\mathbb{E}_1 \left[\sum_{j=1}^{J} \tilde{\beta}_{j-1} u(c_j, \ell_j) - \mathbf{1}_c \lambda_\theta(\theta) + \mathbf{1}_{c,j=1} \lambda_\chi \chi + \tilde{\beta}_{j_b - 1} \nu V_0 \right]$$

where

$$u(c, \ell) = \frac{(c^\mu \ell^{1-\mu})^{1-\gamma}}{1-\gamma}$$

The first term is the expected discounted sum of instantaneous utility depending on consumption $c_j \geq 0$ and leisure $\ell_j \in [0, 1]$ at age j. In general, leisure is a residual time allocation after agents make their choice of working hours and educational effort (if they are currently in college).

The discounting parameter is given by $\tilde{\beta}_j = \beta^j \left(\prod_{k=1}^{j} \zeta_k \right)$, i.e. it accounts for both the time preferences β and survival risk ζ_j. We choose a priori $\gamma = 4$ so that the coefficient of relative risk aversion $\gamma\mu + 1 - \mu \approx 2$ (with μ calibrated in Section 3), as is standard in the literature.[5] Furthermore, agents of age $j \in [j_f, j_b - 1]$ live with their children and so their consumption is discounted by $1 + \zeta$, where ζ is an adult equivalence parameter set equal to $\zeta = 0.3$ (following [Fernández-Villaverde and Krueger, 2007] and [Krueger and Ludwig, 2016]).

The second term stands for the heterogeneous psychic cost of attending college that depends on the in-born ability θ (with $\mathbf{1}_c$ being an indicator function equal to 1 if the newborn enrolls into college).

The third term stands for the (unobservable to the econometrician) college taste χ accruing in the first period of college (with $\mathbf{1}_{c,j=1}$ being an indicator function equal to 1 if the newborn is in the first period of college). Including both the college taste and psychic cost is necessary for the model to match the empirical evidence that, conditional on ability and family income, there is heterogeneity in terms of enrollment decisions.[6]

Finally, the fourth term represents parental altruism introducing motives for inter-vivo transfers. In particular, individuals attach weight ν to their children's expected life-time utility at age 1, V_0. We describe the value function in Section 2.5.

2.3 Production Sector

We assume the existence of a representative firm using capital K and aggregate labor input H in order to produce the final good according to the following production function:

$$F(K, H) = K^{\alpha} H^{1-\alpha}$$

We follow [Katz and Murphy, 1992] by modeling the aggregate labor H as an aggregate of skilled labor H^S and unskilled labor H^U:

$$H = (a^S (H^S)^{\rho} + (1 - a^S)(H^U)^{\rho})^{\frac{1}{\rho}}$$

where a^S is the relative productivity of skilled labor and $\frac{1}{1-\rho}$ is the elasticity of substitution. The latter parameter governs the responsiveness of endogenous skill premium to the relative supply of skilled labor in the economy. We set ρ so that this elasticity equals 1.64, as in [Goldin and Katz, 2009].

[5] Assuming that agents work 1/3 of their time on average, our calibrated parameters imply a Frisch elasticity of $\frac{1}{\mu+\gamma(1-\mu)} \cdot \frac{2/3}{1/3} \approx 0.71$. This elasticity is close to the evidence in [Peterman, 2016], when accounting for the extensive margin of labor supply. The extensive margin is present in our model as we calibrate the model to match the average number of hours in the data including unemployment spells.

[6] Notice that the college taste is a residual of psychic cost $\lambda_{\theta}(\theta)$, which also accounts for correlation between college taste and psychic cost.

Markets for the final good and production inputs are competitive. The rental rate of capital equals $r + \delta$, where r is the interest rate and δ the depreciation rate. Furthermore, the price of a unit of skilled and unskilled labor is given by wages w^S and w^U. Thus, the first order conditions for profit maximization read:

$$r = \alpha \left(\frac{K}{H}\right)^{\alpha-1} - \delta$$

$$w^s = (1-\alpha)a^s \left(\frac{K}{H}\right)^{\alpha} \left(\frac{H}{H^s}\right)^{1-\rho} \quad \text{for} \quad s = S, U.$$

Notice that in our model there are two types of skill relevant for production and three levels of education. Firstly, in line with the literature on the skill premium, we assume that high school graduates provide unskilled labor and that college graduates provide skilled labor. Secondly, we assume that college dropouts provide unskilled labor. Our choice is motivated by empirical evidence in [Torpey and Watson, 2014] who show that only 5% of jobs in the US require "Some college, no degree" or "Associate's degree," implying that most college dropouts take jobs requiring only high school education or less.[7] Because of this, college graduates receive $w^S (\equiv w^{CG})$ per unit of effective labor provided, with high school graduates and college dropouts receiving $w^U (\equiv w^{HS}, w^{CD})$.

Finally, a unit of effective labor supplied is a product of hours worked h_l and current individual labor productivity $\varepsilon_j^e(\theta, \eta)$. The latter depends on the education level e, age j, ability θ and idiosyncratic productivity η, which follows a mean-reverting and education-specific Markov chain $\pi^e(\cdot|\eta)$ with Π^e denoting its invariant distribution. Although we assume that high school graduates and college dropouts provide unskilled labor, our model is flexible enough so that by assuming that $\varepsilon_j^{HS}(\theta, \eta)$ is different from $\varepsilon_j^{CD}(\theta, \eta)$, we will be able to generate a realistic wage premium for dropouts. By capturing positive returns to having 2 years of education, dropouts in our model represent both individuals who fail in 4-year colleges and who enroll into the associate degree programs at 2-year community colleges.

2.4 Financial Markets

The structure of financial markets is incomplete due to the lack of state-contingent claims providing insurance against the college dropout and idiosyncratic productivity shocks. While we allow individuals to self-insure using risk-free assets accruing interest r, they also have access to the government-run loan system providing financial aid for covering the tuition

[7] [Torpey and Watson, 2014] use May 2013 data from the Occupational Employment Statistics survey (employment data) and Employment Projections program (occupational education-level designations) of the U.S. Bureau of Labor Statistics.

fees. As most of student loans in the US are government-provided, we assume no access to private borrowing.[8]

We design the baseline economy such that it matches properties of the US student loan system with fixed repayments in the year 2006, just before the introduction of ICLs through the College Cost Reduction and Access Act of 2007. Our counterfactual economy mimics the US student loan system after the introduction of ICLs.

Fixed Repayments

The properties of student loans in our baseline economy are based on the Stafford federal loan program, which provided up to $\underline{A}^c = \$23,000$ of financial aid in 2006 and is the most popular source of borrowing among undergraduates in the US. In our implementation, we assume that college enrollees in the first period borrow half of the full amount of student loan $0.5\underline{A}^c = \$11,500$. Conditional on passing the first period of college, enrollees borrow the additional $0.5\underline{A}^c$ in period 2.

Repayments are fixed at a constant level in each period such that the present value of fixed repayments over $\bar{T} = 10$ periods (20 years) after leaving college (i.e. starting in period 2 for dropouts, and in period 3 for graduates) equals the present value of the student debt, inclusive of interest. We assume that lenders incur the cost of monitoring borrowers equal to $\iota > 0$ per unit of capital. The no-arbitrage condition for lenders implies that the interest rate on education loans equals $r^- = r + \iota$, with $\iota = 2.3\%$ annually.[9]

This discussion implies that the student loan repayments amount to:

$$\bar{\ell}_{j^*}(e)^F = \begin{cases} 0.5\underline{A}^c \cdot \frac{\left(1+r^-\right)^{\bar{T}}}{\left(1+r^-\right)^{\bar{T}}-1} \cdot r^- & \text{if } e = CD \text{ and } j^* \leq \bar{T} \\ \underline{A}^c \cdot \frac{\left(1+r^-\right)^{\bar{T}}}{\left(1+r^-\right)^{\bar{T}}-1} \cdot r^- & \text{if } e = CG \text{ and } j^* \leq \bar{T} \\ 0 & \text{otherwise} \end{cases} \tag{1}$$

where j^* is the number of periods after leaving college ($j^* = j - 2$ for CD and $j^* = j - 3$ for CG).

Our choice of $\bar{T} = 10$ (20 years) may seem at odds with the fact that the statutory repayment length of student loans under the standard repayment scheme is 10 years. However, we

[8]Nonfederal student loans constitute less than 10% of undergraduate borrowing in the past years and constituted less than 25% at the peak in the mid-2000s [Baum et al., 2019]. Moreover, Stafford loans can be either subsidized or unsubsidized (with government paying for the loan interest while in college, or not). In our quantitative framework students start making their repayments only after they leave the college, so we effectively focus our analysis on subsidized loans.

[9]We choose the value of interest rate premium based on the U.S. Department of Education's Federal Register Vol. 83 No. 207 from 25.10.2018 available under: https://fsapartners.ed.gov/sites/default/files/attachments/fregisters/FR102518VariableRateFFELJuly12010.pdf

extend it by additional 10 years in line with the evidence in [Scherschel, 1998], who shows that many borrowers are consolidating their student debt under Chapter 13 in order to repay them over 12-30 years.[10]

While not every enrollee borrows up to the student loan limit in reality, we make this modeling choice in order to simplify computations. Doing so is not as restrictive as it appears, because we allow agents to save aside in a risk-free asset accruing interest rate r in all periods of their life. In particular, because the interest rates between saving and student borrowing are very close to each other (since $\iota = 2.3\%$), this approach is arguably without loss of generality, as agents can offset any undesirable borrowing through higher saving positions.

ICL Reform

We base our modelling of the reform on the current design of income-driven repayment plans in the US [CBO, 2020]. Intuitively, the ICL reform lowers the workers' repayment risk due to the uninsurable college dropout and idiosyncratic productivity shocks. It does so by introducing a non-linear repayment schedule where workers with a labor income below the poverty threshold $\bar{y}$ do not face any repayments in a given period, and those with income above $\bar{y}$ repay the ω-portion of it (up to an upper repayment limit).

In particular, we assume that agents' repayments at any age j are given by the following:

$$\bar{\ell}_{j^*}(e,y)^{ICL} = \begin{cases} \min\{\omega \cdot \max\{0, y-\bar{y}\}, \bar{\ell}_{j*}(e)^F\} \text{ if } j^* \leq \bar{T} \\ 0 \text{ otherwise} \end{cases} \tag{2}$$

where j^* is defined as in (1) and $\bar{T} = 10$ stands for the number of repayment periods (the same as under fixed repayments), $\bar{y}$ is 150% of the federal poverty threshold equal to \$20,000, i.e. $\bar{y}$=\$30,000, and $\omega = 10\%$ is the statutory repayment rate on the discretionary part of income, i.e. on the before-tax labor income earned in excess of $\bar{y}$.

Importantly, any outstanding debt is forgiven after the period $\bar{T}$. This important feature provides insurance to the very unlucky agents experiencing many low productivity shocks who would be unable to repay their student debt under the fixed repayment system.

Finally, the ICL repayments $\bar{\ell}_{j*}(e,y)^{ICL}$ are capped in every period at the level of fixed repayments $\bar{\ell}_{j*}(e)^F$.

[10] The same assumption on the length of student debt repayments under the fixed repayment scheme has been employed in [Daruich, 2018] and [Abbott et al., 2019].

2.5 Individual Problems

In what follows, we present the recursive formulation of the decision problems faced by agents during the education, working and retirement stages of their life in our economy.[11]

Enrollment Stage

Just before becoming independent in period $j = 1$ (after leaving high school), agents make their first decision about enrolling into college. Denoting by V_0 the associated value function, this problem takes the following form:

$$V_0(a, \theta, \eta, \chi) = \max\{\underbrace{V_1^c(a, \theta, \eta) + \lambda_\chi \chi}_{\text{enrolling}}, \underbrace{V_1(a, HS, \theta, \eta)}_{\text{not enrolling}}\} \tag{3}$$

which depends on a - the agent's assets endogenously determined as a transfer from parents, θ - her stochastically inherited ability, η - her current idiosyncratic labor productivity, and χ - her college taste shock.

The value of enrolling is given by the expected value of being in college V_1^c with the associated taste shock $\lambda_\chi \chi$, and the value of not enrolling is given by the value of working as a high school graduate V_1.

Education Stage: First Period

The value of enrolling into college V_1^c is given by:

$$V_1^c(a, \theta, \eta) = \max_{c, h_l, h_e, a'} u(c, 1 - h_l - h_e) - \lambda_\theta(\theta)$$
$$+ \beta \mathbb{E}_{\eta'}(p(h_e; \theta) \underbrace{V_2^c(a', \theta, \eta')}_{\text{advance}} + (1 - p(h_e; \theta)) \underbrace{V_2(a', CD, \theta, \eta')}_{\text{dropout}})$$

subject to:

$$c + a' + \varphi - s = w^U \varepsilon_1^{HS}(\theta, \eta) h_l + a + 0.5\underline{A}^c - T(c, a, w^U \varepsilon_1^{HS}(\theta, \eta) h_l)$$

$$p(h_e; \theta) = 1 - \exp(-p_\theta(\theta) h_e)$$

$$a' \geq 0, \;\; c \geq 0, \;\; 0 \leq h_l + h_e \leq 1, \;\; h_l \in [0, 1], \;\; h_e \in [0, 1], \;\; \eta' \sim \pi^e(\cdot|\eta)$$

Attending the first period of college is associated with paying the tuition fee net of subsidies $\phi - s$ and borrowing of $0.5\underline{A}^c$ for the first period of their college education. Furthermore,

[11] Although college enrollees can also work, we call individuals who are not in college and are not retired "workers." Likewise, we call this period the "working stage."

agents with in-born ability θ who decide to attend college have to bear the psychic cost $\lambda_\theta(\theta)$ and choose educational effort h_e in order to increase their probability $p(h_e;\theta)$ of advancing into the second period of college and graduating. The fact that graduation remains stochastic given the effort taken captures residual uncertainty such as learning about own ability, enjoyability in college, health, financial shocks and so on.

Importantly, because the risk of dropping out with a student debt limits enrollment of marginal individuals, ICLs will stimulate it by attaching repayments to the current level of income. This insurance, however, triggers moral hazard: as the dropout risk is reduced, the very same policy intervention may diminish the attractiveness of a successful graduation, weakening the incentives for exerting educational effort and so lowering the graduation. Appendix A contains a formal exposition of this trade-off in a simple two-period model with risky education, endogenous enrollment and educational effort, and moral hazard.

Furthermore, students decide about their savings $a' \geq 0$ in a risk-free asset accruing interest rate r. Additionally, students may generate some income by supplying labor hours h_l as high school graduates. Finally, they also have to pay the total tax $T(c, a, y)$, which depends on their consumption, current assets and earnings.

In general, higher initial assets a make enrollment more likely as they reduce the financial cost of education. Higher taste shock χ makes enrollment more likely by increasing the utility from being in college. Through reducing the psychic cost and increasing their future income, higher ability θ increases returns to educational effort h_e. By increasing the value of outside option associated with immediately entering the labor market, higher age-1 idiosyncratic productivity η reduces enrollment.[12]

Based on evidence in "Trends in College Pricing, 2006" and "Student Financing of Undergraduate Education: 2007-2008", we assume that (i) annual governmental subsidies for college education are universal and equal $s = \$1,183$;[13] and (ii) annual tuition fee (net of institutional grants) is $\varphi = \$11,018$.[14]

[12]Although in our calibration below we find a high empirical persistence of idiosyncratic shocks, we capture their impact on outside option by assuming that they are reset for agents who enroll into college.

[13]According to Table 3.2 of "Student Financing of Undergraduate Education: 2007-2008," 27.6% of college enrollees have received federal subsidies of \$2,800 on average, which leads to \$773. On the other hand, the share of state subsidies' receivers is 16.4% with the average amount of \$2,500 (Table 3.3), which leads to \$410. This gives $s = \$1,183$ annually.

[14]The tuition and fees for enrollees at public and private universities is \$5,836 and \$22,218 from Table 1 in "Trends in College Pricing, 2006." The cost of books and supplies for enrollees at public and private universities is \$942 and \$935 from Table 2 of "Trends in College Pricing, 2006." Since the share of enrollees for each type is 68% and 32% (Figure 10 in "Trends in College Pricing, 2006"), the average tuition and fees are \$12,018. Moreover, because institutional grants on average amount to \$5,000 and are received by 20% of students (Table 3.4 in "Student Financing of Undergraduate Education: 2007-2008"), our estimate of average net tuition is \$11,018 annually.

Education Stage: Second Period

As was already mentioned, students proceed successfully into the second half of their college education with probability $p(h_e;\theta)$. In this case, their value function takes the following form:

$$V_2^c(a,\theta,\eta) = \max_{c,h_l,a'} u(c, 1-h_l-\bar{h}_e) - \lambda_\theta(\theta) + \beta\mathbb{E}_{\eta'} \underbrace{V_2(a', CG, \theta, \eta')}_{\text{work as CG}}$$

subject to:

$$c + a' + \varphi - s = w^U \varepsilon_2^{CD}(\theta,\eta)h_l + a + 0.5\underline{A}^c - T(c, a, w^U\varepsilon_2^{CD}(\theta,\eta)h_l)$$

$$a' \geq 0,\ \ c \geq 0,\ \ 0 \leq h_l + \bar{h}_e \leq 1,\ \ h_l \in [0,1],\ \ \eta' \sim \pi^e(\cdot|\eta).$$

We assume that once students enter the second period of college, they graduate with certainty. Completing the college requires additional borrowing of $0.5\underline{A}^c$. Furthermore, in line with evidence in [Babcock and Marks, 2011], it takes a fixed amount of educational effort (as opposed to the first period), equal to the fifth of students' time endowment, i.e. we set $\bar{h}_e = 0.20$.[15] Finally, advanced students can provide part-time labor with the productivity level of college dropouts.

Working Stage

The Bellman equation for working stage[16] of individuals looks as follows:[17]

$$V_j(a,e,\theta,\eta) = \max_{c,h_l,a'} u\left(\frac{c}{1+\mathbf{1}_{\mathcal{J}_f}\zeta}, 1-h_l\right) + \beta\mathbb{E}_{\eta'|\eta}V_{j+1}(a',e,\theta,\eta')$$

subject to

$$c + \bar{\ell}_j^* + a' = w^e\varepsilon_j^e(\theta,\eta)h_l + (1+r)a - T(c,a,w^e\varepsilon_j^e(\theta,\eta)h_l)$$

$$a' \geq 0,\ \ c \geq 0,\ \ 0 \leq h_l \leq 1,\ \ \eta' \sim \pi^e(\cdot|\eta)$$

where $\mathbf{1}_{\mathcal{J}_f}$ is an indicator function equal to one when individuals live with their children ($j \in [j_f, j_b - 1]$) and $\bar{\ell}_j^* \in \{\bar{\ell}_{j*}(e)^F, \bar{\ell}_{j*}(e, w^e\varepsilon_j^e(\theta,\eta)h_l)^{ICL}\}$ is the per-period repayment

[15] This number is derived as a share of the studying time equal to 35.6 hours in 32 weeks (of fall and spring semesters) in the annual discretionary time endowment of 5,824 hours (52 weeks with 16 hours of discretionary time per day). This is also in line with the assumption in [Hendricks and Leukhina, 2018].

[16] Precisely, periods $j \in [1, j_r - 1]$ for high school graduates, $j \in [2, j_r - 1]$ for college dropouts and $j \in [3, j_r - 1]$ for college graduates.

[17] After retirement, idiosyncratic labor productivity shocks are no longer a state variable. Thus, the Bellman equation for the last period of workers is $V_{j_r-1}(a,e,\theta,\eta) = \max_{c,h_l,a'} u(c, 1-h_l) + \beta V_{j_r}(a',e,\theta)$.

depending on the institutional setup. The loan repayment $\bar{\ell}^*_j$ will be zero for high school graduates in all periods and for workers with college education from the $\bar{T}+1^{st}$ period after finishing their education. Finally, notice that the dependence of $\bar{\ell}_{j*}(e, w^e \varepsilon^e_j(\theta,\eta)h_l)^{ICL}$ on h_l implies that ICLs discourage labor supply, i.e. the reform distorts the intratemporal consumption-leisure optimality condition.[18]

Inter-vivo Transfer Stage

When agents reach age j_b, their offspring becomes independent. At the same time, their ability θ' becomes known after being drawn from the Markov chain $\pi_\theta(\theta,\theta')$. Because parents value expected life-time utility of their children, they make another decision about the size of inter-vivo transfers b. Thus, in this period the Bellman equation reads:

$$V_{j_b}(a,e,\theta,\theta',\eta) = \max_{c,h_l,a',b} u(c,1-h_l) + \beta \mathbb{E}_{\eta'|\eta} V_{j_b+1}(a'-b,e,\theta,\eta') + \nu \mathbb{E}_{\eta'',\chi} V_0(b,\theta',\eta'',\chi)$$

subject to:

$$c + a' = w^e \varepsilon^e_j(\theta,\eta)h_l + (1+r)a - T(c,a,w^e\varepsilon^e_j(\theta,\eta)h_l)$$

$$a' \geq 0, \;\; c \geq 0, \;\; 0 \leq h_l \leq 1$$

$$\eta' \sim \pi^e(\cdot|\eta), \;\; \eta'' \sim \Pi^{HS}, \;\; \chi \sim N(0,1).$$

Parents do not observe their children's initial idiosyncratic productivity η'' (drawn from Π^{HS}) nor their college taste χ (drawn from the standard normal distribution). However, since they know the children's ability θ', our model can account for the impact of expected college enrollment decisions on parental transfers.

Retirement Stage

Workers retire at the beginning of age j_r. After this, they survive stochastically until the maximum age of J, provide no labor and live off their assets and pension benefits. In this case, the Bellman equation reads:

$$V_j(a,e,\theta) = \max_{c,a'} u(c,1) + \beta \zeta_j V_{j+1}(a',e,\theta)$$

subject to:

$$c + a' = (1+r)\zeta^{-1}_{j-1}a + P(e,\theta) - T(c,\zeta^{-1}_{j-1}a,0)$$

[18] The distortion in the consumption-leisure allocation enters through the "tax-like" ω-term in the FOC: $\frac{u_l}{u_c} = \frac{(1-\tau_l)(1-\omega)w^e\varepsilon^e_j(\theta,\eta)}{(1+\tau_c)}$

$$a' \geq 0, \;\; c \geq 0.$$

where $P(e, \theta)$ denotes retirement benefits modelled as in the US with pension entitlement being a function of life-time labor earnings (i.e. of ability θ and education level e). See Appendix D for details on calibrating the pension system.

Furthermore, we assume the existence of perfect annuity markets redistributing assets of deceased individuals within their current cohorts. For this reason, assets are inflated by ζ_{j-1}^{-1}.

2.6 Government

As a final building block of the model, there is a government running welfare programs and a tax system funding it. In particular, the government's revenue is made of the student loan repayments and the net tax proceeds collected through the function $T(c, a, y) = \tau_c c + \tau_k r a + \tau_l y - \psi$, where ψ is the lump-sum transfer (given to each individual) introducing progressivity into the labor income tax schedule. Based on [McDaniel, 2007], we assume $\tau_c = 0.08$ and $\tau_k = 0.29$.

On the expenditure side, the government finances disbursements of student loans to enrollees, college subsidies and retirement benefits.[19] Similarly, the tax revenue funds the exogenous stream of government consumption $G_c = gY$, where Y stands for the aggregate output. Because the government consumption and investment in the US in 2006 amounted to 17.8% of GDP (according to data from the U.S. Bureau of Economic Analysis (BEA)), and the government expenditure on tertiary education in 2000 was 0.9% of GDP (according to data from the Organisation for Economic Co-operation and Development (OECD)), we set g equal to $17.8\% - 0.9\% = 16.9\%$.

The model is closed with a government budget-balance condition stipulating that in each period the total tax revenue equals the total government spending. We use the labor income tax rate τ_l to balance the budget in each period.

2.7 Competitive Equilibrium

We focus our attention on a stationary competitive equilibrium in which the cross-sectional allocation is invariant. As already mentioned, the equilibrium includes J overlapping generations of which each individual maximizes her expected life-time utility, the representative firm maximizes profits, the government budget is balanced and prices clear all the markets.

[19] For details on the government budget constraint, see Appendix B.

See Appendix B for the formal definition of stationary equilibrium and Appendix C for the description of numerical algorithm employed.

3 Calibration

This section describes how we discipline our model. Our strategy is to choose parameters such that the economy matches key properties of the US economy in the year 2006, before introduction of the College Cost Reduction and Access Act of 2007. First, we estimate parameters of the labor productivity process. Then, we employ the simulated method of moments for all the other parameters, such as the ones governing the preferences, graduation probability function and lump-sum transfer.

Importantly, we normalize prices such that the average annual income of high school graduates at age 48 is $51,741, as in 2006.

3.1 Labor Productivity Process

We estimate the labor productivity for an individual of age j with ability θ, current shock η, education level e using the following process:

$$\ln \epsilon_j^e(\theta, \eta) = \ln \epsilon^e + \ln \psi_j^e + \epsilon_\theta^e \theta + \ln \eta.$$

First, we normalize $\epsilon^{HS} = \epsilon^{CG} = 1$ and calibrate ϵ^{CD} to match the wage premium of college dropouts, as explained later in Section 3.3. Second, we assume that ability θ takes one of the values on four grid points, which are equal to the median of ability at each quartile of the ability distribution in NLSY79. Our empirical proxy for ability is the Armed Forces Qualification Test (AFQT) score in the NLSY79.

Then, using the PSID, we estimate the age profile ψ_j^e of workers with age j and education level e (see Appendix E for sample selection and estimated age profile parameters).[20]

In order to identify the effect of ability on labor productivity, we first subtract from hourly wages of each individual in the NLSY79 the age profile estimated using the PSID, and then we regress these pruned hourly wages on ability measured by the log of AFQT80. Table 1 reports the estimated coefficients. Consistent with the literature (e.g. [Low et al., 2010]), we find that individuals with higher ability have higher returns to education.

For estimation of the process for idiosyncratic shocks η, we assume that they follow the education-specific AR(1) process:

[20] We use the PSID because it starts from a nationally representative cross-section and the average age of its sample does not change with the calendar year.

	HS	CD	CG
log AFQT	.582	.647	1.08
	(.32)	(.32)	(.24)

Table 1: Estimated ability slope ϵ^e_θ of labor productivity

Source: NLSY79. See Appendix E for details.

$$\ln \eta' = \rho^e \ln \eta + \epsilon_\eta, \quad \epsilon_\eta \sim N(0, \sigma^{e2}_\eta).$$

Our empirical measure of η-shocks are residuals of the regression for the age profile, using the same PSID sample where ability is captured by the fixed effect (and so we do not need to use the AFQT-ability variable from NLSY79).

In our quantitative model, we approximate this process using the education-specific Markov chain $\pi^e(\eta'|\eta)$ with two education-specific states η^e_H and η^e_L. We choose the chain's parameters such that it has the same persistence and conditional variance as the AR(1) process above. In particular, we estimate it using a minimum distance estimator with a fixed effect and a measurement error, targeting moments such as covariances of the wage residuals (after filtering out the age effects) at different lags and age groups, separately for each education level. In Appendix E, we discuss sample selection and details of the estimation procedures. Table 2 presents results of the estimation.

Note that we abstract from unemployment shocks. In the US, the mean unemployment duration is rather short (equal to approximately 16.5 weeks in 2006),[21] with the unemployed ones usually qualifying for unemployment benefits.[22] Furthermore, borrowers can delay their repayments by up to 270 days (without entering default), which can be further delayed upon declaring bankruptcy on student debt under Chapter 13. Since these observations suggest that unemployment shocks occurring in any period (equal to 2 years in our model) can be smoothed relatively well within this very period, we do not explicitly model unemployment shocks. Instead, we target in our calibration 1/3 share of the workers' discretionary time being spent in work. This choice is motivated by our finding in the PSID that workers supply approximately 39 hours per week on average in the long-run including periods of unemployment, with very little variation between education groups. Nonetheless, our model can arguably account for unemployment as it allows unproductive agents to endogenously

[21]See the data from FRED: https://fred.stlouisfed.org/series/UEMPMEAN

[22]Unemployment benefits in the US amount to 50-60% of past wage income (depending on the state) and are paid for 26 weeks (with possible extensions under Emergency Unemployment Compensation or Extended Benefits programs). See e.g. [Mazur, 2016] for analysis of the unemployment insurance system in the US.

	HS	CD	CG
ρ^e	0.9390	0.9620	0.9439
σ_η^{e2}	0.0164	0.0204	0.0260

Table 2: Estimated parameters of the residual labor productivity process

Source: PSID. See Appendix E for details.

reduce their labor supply.[23,24]

3.2 Intergenerational Ability Transmission

The Markov chain for intergenerational transmission of ability $\pi_\theta(\theta, \theta')$ is estimated using NLSY79 and "NLSY79 Child & Young Adult." For the empirical measures of ability, we use test scores achieved in AFQT for parents and in PIAT for children. The correlation between parents' and children's abilities is positive, capturing both the genetic transmission of ability and empirical patterns of high income parents investing more into early education of their children.[25] In Appendix F, we discuss the sample selection, details of the estimation procedure and provide the estimated Markov chain's parameters in Table 9.

3.3 Remaining Parameters

We finalize the calibration of remaining parameters using the simulated method of moments. The algorithm chooses jointly values for remaining 15 parameters (listed in the second part of Table 3) as to minimize the average Euclidean percentage deviation of the 18 model-generated moments (listed in Table 4).

Since the equilibrium of the model is complex, in some cases one parameter may affect many targeted moments. Nonetheless, enrollment rates across ability and family income help identify the parameters of the psychic cost and taste functions λ_θ and λ_χ. Similarly, graduation rates across ability help identify parameters of the graduation probability function $p(h_e; \theta)$. The data on enrollment and graduation rates comes from NLSY97. Since majority

[23] Another significant risk faced by workers throughout their life-time are health shocks. As mentioned above, we model death risk with stochastic survival probabilities once agents enter their retirement. Other ways of modelling health shocks include persistent drops in productivity or unexpected expenditures on health care. Since these health risks are less relevant for young workers, we do not model them in order to keep our quantitative framework tractable.

[24] Ignoring unemployment and search arguably leads to a conservative estimate of the ICLs' welfare impact: [Ji, 2020] shows that the policy generates welfare gains by allowing for more efficient matching in labor markets.

[25] See [Cunha and Heckman, 2007], [Cunha, 2013] and [Daruich, 2018].

parameter	interpretation	value	target/source
		externally determined	
γ	coefficient of relative risk aversion	4	modelling choice, CRRA=2
ζ	adult equivalence scale	0.3	literature
α	capital share of GDP	33.3%	literature
δ	depreciation (annual)	7%	Kruger and Ludwig (2016)
ρ	elasticity of substitution in production	0.39	elast.=1.64, Katz and Murphy (1992)
$\epsilon^{CG}, \epsilon^{HS}$	prod. intercept for CG, HS	1	normalization
ψ_j^e	labor prod. at age j for $e \in \{HS, CD, CG\}$	Estimates	Appendix E, PSID
ϵ_θ^e	e-specific effect of ability on prod.	(0.58,0.65,1.08)	Appendix E, NLSY 79
ρ^e	e-specific persistence of idiosyn. shocks	(0.94,0.96,0.94)	Appendix E, PSID
$\sigma_\eta^{2,e}$	e-specific variance of idiosyn. shocks	(0.02,0.02,0.03)	Appendix E, PSID
$\bar{h}_e$	studying time of advanced students	0.20	Babcock and Marks (2011)
ι	Stafford interest premium (annual)	2.3%	US Department of Education
$\underline{A}^c$	Stafford borrowing constraint	\$23,000	US Department of Education
$\bar{y}$	ICL poverty threshold	\$30,000	150% of 2000 fed poverty level, CBO (2020)
ω	ICL repayment rate	10%	CBO (2020)
$\bar{T}$	student loan repayment period	20 years	CBO (2020), Scherschel (1998)
φ	net tuition fee (annual)	\$11,018	College Board, US Dept. of Education
s	government college subsidies (annual)	\$1,183	US Dept. of Education
τ_c	consumption tax rate	8%	McDaniel (2007)
τ_k	capital income tax rate	29%	McDaniel (2007)
g	gov cons.+investment-edu./GDP	17%	BEA, OECD
		internally determined (jointly using SMM)	
$p_\theta(\theta)$	θ-dependent slope of graduation prob. f-n	(1.10, 0.802, 0.947, 1.20)	grad. profile, Fig. 2/NLSY97
$\lambda_\theta(\theta)$	θ-dependent psychic cost	(-6.02, -14.7, -21.8, -25.0)	enrol. profile, Fig. 2/NLSY97
λ_χ	college taste-slope	32.7	enrol. profile, Fig. 2/NLSY97
a^S	productivity of skilled labor	0.504	CG-HS skill premium, CPS
ϵ^{CD}	productivity intercept of CD	1.08	CD-HS wage premium, CPS
μ	consumption share of preference	0.408	7.5 hours of work per day
β	time discount rate	0.948	capital/output ratio, F.-V. and K. (2011)
ν	altruism parameter	0.113	transfer/mean income at 48, Daruich (2018)
ψ	lump-sum transfer	0.0335	log pre-tax/post-tax income, HPV (2010)

Table 3: Calibration summary

Moment	Model	Data
Enrollment rate of ability quartile	(Figure 2)	(Figure 2)
Graduation rate of ability quartile	(Figure 2)	(Figure 2)
Enrollment rate of family income quartile	(Figure 2)	(Figure 2)
Skill premium for CG	90.0%	90.2%
Wage premium for CD	19.9%	19.9%
Hours of work	33.3%	33.3%
Aggregate capital / output	1.31	1.33
Inter-vivo transfer / mean income at 48	72.1%	72.1%
Var log post-tax / var log pre-tax income	0.61	0.61

Table 4: Moments matched and model fit

of enrollment into 2-year colleges is driven by the option value of transferring into 4-year colleges (see [Trachter, 2015]), our measure of enrollment rate includes both types of colleges and we count graduates of 2-year degrees as college dropouts.[26]

Then, we estimate the wage premia of college graduates and college dropouts using the CPS data. These two moments help to identify the remaining parameters of labor productivity (a^S, ϵ^{CD}).

Finally, moments from the 6th to 9th rows in Table 4 are associated with the utility parameters μ, β, ν and the lump-sum transfer parameter ψ.[27]

3.4 Calibration Validation

Table 4 presents the empirical fit of our estimation strategy. Overall, the quantitative economy fits the data very well, considering the over-identification of 15 parameters against 18 moments.

Our empirical approach is further validated by the model's responses along non-targeted margins. First of all, although we have not included the pattern of graduations along income quartiles in Figure 2 as targeted moments, the model matches the evidence well.

Second, our estimation implies that the mean educational effort in the first period of college amounts to 23.8% of students' discretionary time. This number is very close to the evidence in [Babcock and Marks, 2011] suggesting that students spend on average 20% of their time studying.

Third, we validate our model's predictions through implementation of two experiments

[26] See also work by [Hendricks and Leukhina, 2017], [Hendricks and Leukhina, 2018] and [Athreya and Eberly, 2020] following a similar approach.

[27] The transfer from parents is taken from [Daruich, 2018], who uses the PSID data. The ratio of variance of the pre-tax cross-sectional income to the post-tax equivalent of it is from [Heathcote et al., 2010].

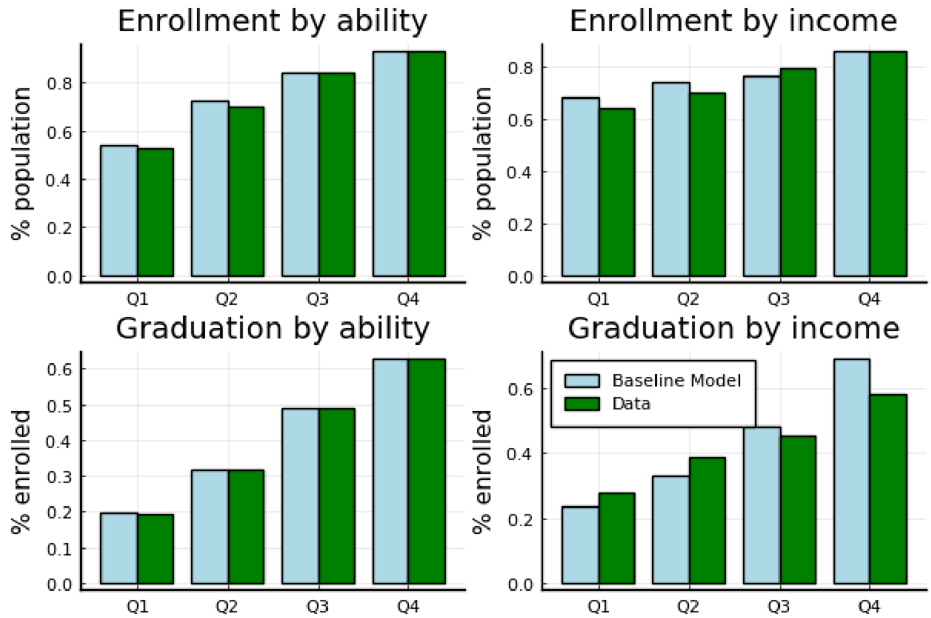

Figure 2: Enrollment and graduation rates by ability and income quartiles

Data source: NLSY97. We restrict the sample to 25-year-old high school graduates. Enrollment includes both 2- and 4-year colleges. Graduation includes only graduates of 4-year colleges. Ability is the log of AFQT score using the definition from the NLSY79. Scores are adjusted by age, as in [Altonji et al., 2012] and [Castex and Dechter, 2014]. Family income is defined as the average of parental income at 16 and 17 if both are available. We use one if both are not available.

conducted in partial equilibrium, where all prices and the distribution at age 1 are fixed. The aim is to compare the implied responses of enrollment and graduation in our model to the ones documented in the literature. We begin by increasing the student loan limits by \$450 in each year of college, and then we introduce a \$1,000 increase in subsidies for all years in college.[28] Table 5 contains results of these exercises together with the relevant empirical estimates. Relaxing borrowing constraints leads to no change in enrollment rate and a 0.9 p.p. increase in the graduation rate. The lack of effect on enrollment is in line with findings in [Keane and Wolpin, 2001], [Carneiro and Heckman, 2002], [Cameron and Taber, 2004], [Johnson, 2013] and [Denning, 2019].[29] The effect on graduation is close to the estimates of 1.0 p.p. in [Johnson, 2013] and 2.1 p.p. in [Black et al., 2020].[30]

[28] In both experiments the additional financial aid is given to the current and all future generations.

[29] [Denning, 2019] shows that an increase in the combined financial aid of \$1,400(=\$900 in grants + \$500 in loans) did not increase the college enrollment of Texas students. [Keane and Wolpin, 2001] and [Johnson, 2013] estimate structural models and find that increasing borrowing limits substantially barely moves the enrollment. For instance, [Johnson, 2013] finds a ≈1.0 p.p. increase in the share of people enrolled on impact of a \$6,000 increase in the borrowing limit, leading to a ≈0.3 p.p. increase in our exercise. Similar conclusions are reached in empirical work of [Carneiro and Heckman, 2002] and [Cameron and Taber, 2004].

[30] [Johnson, 2013] finds a ≈2.4 p.p. increase in the share of people with a college degree upon increasing the borrowing limit by \$6,000, translating into an ≈0.7 p.p. increase in the share of graduates in our \$1,800

Increase in the borrowing limit by $450 annually		
	literature	simulated
Δ enrollment	0.0 p.p - 0.3 p.p.[a]	0.0 p.p.
Δ graduation	1.0 p.p. - 2.1 p.p.[b]	0.9 p.p.

Increase in subsidies by $1,000 annually		
	literature	simulated
Δ enrollment	0.0 p.p. - 6 p.p.[c]	0.7 p.p.
Δ graduation	2.2 p.p.[d]	2.4 p.p.

Table 5: Comparison of empirical and simulated moments

Note: Table reports the partial equilibrium impact of increasing borrowing limits and subsidies on enrollment and graduation rates and their empirical counterparts. Literature in (a) refers to [Keane and Wolpin, 2001], [Carneiro and Heckman, 2002], [Cameron and Taber, 2004], [Johnson, 2013] and [Denning, 2019]. Literature in (b) refers to [Johnson, 2013] and [Black et al., 2020]. Literature in (c) refers to [Kane, 1995], [Cameron and Heckman, 2001], [Dynarski, 2002], [Turner, 2017], [Marx and Turner, 2018], [Carruthers and Welch, 2019]. Literature in (d) refers to [Denning et al., 2019].

Furthermore, increasing subsidies by $1,000 annually leads to a 0.7 p.p. increase in the enrollment rate and a 2.4 increase in the graduation rate. Results in the literature about the response of enrollment margin are very diverse and range from no response to large increases up to 6 p.p.[31] The response of graduation rate on impact of subsidies is very much in line with the evidence in [Denning et al., 2019].[32] Overall, the validation results above build confidence in the estimates of key elasticities driving the enrollment and graduation margins in our model.

Fourth, Figure 9 in Appendix G shows that the implied profiles of consumption, earnings and asset margins capture the relevant aspects of life-cycle correctly. In particular, the labor hours supplied follow a well-documented hump-shaped pattern (see e.g. [Kaplan, 2012]), with level adjustments in periods when children are born and when they leave their parents. This comes from the estimated hump-shaped earnings profile with increases in income being larger for more educated individuals, as documented by e.g. [Low et al., 2010]. Likewise, the changes in the variance of log earnings over the life-cycle match the empirical patterns

experiment (and so ≈1 p.p. increase in the graduation rate). [Black et al., 2020] reports a 4.3 p.p. impact of a $1,800 increase in the student loan availability over all years of college for ≈50% of Texas Sample population that was credit constrained, hence the moment of 2.2 p.p.

[31] Large responses of the enrollment margin (between 3 p.p. - 6 p.p.) were found in [Cameron and Heckman, 2001] and [Dynarski, 2002]. However, [Kane, 1995], [Turner, 2017], [Marx and Turner, 2018], [Carruthers and Welch, 2019] and [Denning, 2019] find no impact of Pell grant eligibility or of increases in the grant amounts for college enrollment.

[32] [Denning et al., 2019] estimate that a $700 increase in the annual Pell grant aid leads to a 1.5 p.p. increase in the graduation rate after 4 years from the time of enrollment, implying an increase of approx. 2.1 p.p. for the $1,000 experiment.

in [Guvenen, 2009]. Therefore, our model not only generates a realistic behavior of agents while in college, but also along their life-cycle.

Finally, although we have only targeted a single moment of the log pre-tax income variance to log post-tax income variance ratio for calibrating the lump-sum transfer ψ, the implied average effective income tax rates are in line with the empirical evidence on effective tax rates in the US in [Heathcote et al., 2017] (see Figure 7 in Appendix G).[33] This suggests that the degree of tax progressivity in our economy is realistic, and as such this validates the overall policy environment that we use for the welfare evaluation of ICLs.

4 Results

In this section, we discuss main quantitative results of the paper. We begin by evaluating the equilibrium impact of the reform introducing ICLs in the US. By comparing the ex-ante welfare of the newborn population in two steady states, we show that ICLs generate a significant welfare improvement. Additionally, we vary the parameters of the ICL system and find that the effectiveness of ICLs can be significantly enhanced through introduction of a poverty threshold below which workers make no repayments, and of a maximum earnings threshold above which repayments do not increase anymore.

4.1 Evaluating the US ICL System

Table 6 presents the impact of the reform introducing ICLs on the US economy. Our social welfare measure are consumption-equivalent changes in utilitarian welfare of newborn agents in the steady state. We find that on average these gains are equivalent to a 0.82% permanent increase in consumption. Importantly, while the reform changes significantly neither the aggregate output nor capital, it reduces the skill premium by 3.6 p.p. (or 4%) and parental transfers by $1,272 (or 3%) on average. It also generates additional fiscal costs, as the labor income tax rate increases by 0.4 p.p. (or 1%) in order to make up for the forgiven debt and small reductions in labor hours supplied.

We can improve our understanding of the effects triggered by the reform by looking at the education sector. As higher education becomes less risky and subsidized, ICLs increase college enrollment by 3.3 p.p. (or 4.4%). However, the reform induces some adverse selection:

[33] Using data from the PSID combined with TAXSIM program, [Heathcote et al., 2017] approximate in Figure 1.b the ratio of post- to pre-government income. Their pre-government (taxable) income includes labor and self-employment income, private transfers, plus income from interest, dividends and rents, minus expenses that are deductible in the US. Their post-government income is made of the pre-government income minus taxes, plus public cash transfers.

Statistic	**Fixed**	**ICL**	**ICL** control h_e	**ICL** control h_e & h_l
Welfare				
Average cons.-eq. welfare gain		+0.82%	+0.90%	+1.02%
↪ *Share due to the uncertainty effect*		*46%*	*37%*	*34%*
↪ *Share due to the level effect*		*41%*	*51%*	*52%*
↪ *Share due to the inequality effect*		*13%*	*12%*	*14%*
Average cons.-eq. welfare gain for HS		-0.19%	-0.11%	+0.11%
Average cons.-eq. welfare gain for CD		+1.73%	+1.82%	+2.03%
Average cons.-eq. welfare gain for CG		+1.13%	+1.11%	+1.25%
Education sector				
Share of college enrollees	75.3%	78.6%	78.6%	78.5%
Share of college graduates	32.3%	33.1%	33.1%	33.1%
Skill premium	90.0%	86.4%	86.5%	85.8%
Educational effort	23.7%	23.2%	23.2%	23.2%
Mean ability of enrollees	5.15	5.14	5.14	5.14
Mean parental transfer	$37,291	$36,019	$36,032	$35,536
Average net worth of CG	-$2,975	-$6,138	-$6,064	-$7,214
Average net worth of CD	$4,912	$2,960	$3,328	$3,107
Average net worth of HS	$24,519	$25,614	$25,591	$25,627
Borrowers qualifying for ICLs	N/A	47.9%	47.8%	47.7%
Mean repayment by CG	$2,145	$1,355	$1,356	$1,500
Mean repayment by CD	$1,012	$507	$507	$509
Labor income tax rate	35.2%	35.6%	35.6%	35.5%
Production sector				
Aggregate output	0.283	0.283	0.283	0.284
Aggregate capital	0.372	0.370	0.370	0.371
Interest rate r	5.8%	5.8%	5.8%	5.8%
Labor hours of CG	36.5%	35.5%	35.6%	36.2%
Labor hours of CD	33.3%	33.0%	33.0%	33.0%
Labor hours of HS	31.6%	31.5%	31.6%	31.6%

Table 6: Aggregate statistics of economies without and with ICLs, without and with controlling educational effort or labor supply

Note: "Average cons.-eq. welfare gain" is computed before enrollment decisions are made and it includes the changes in the composition of agents across states. The "Average cons.-eq. welfare gain for e" ($e \in \{CD, CG, HS\}$) are computed at the beginning of period 2, after the enrollment decisions are made and dropout shock is realized. All three latter metrics control for compositional changes by fixing the masses of agents at the pre-reform level. "Average net worth of e" is computed as current asset position of agents minus student debt taken ($11,500 for CDs and $23,000 for CGs plus interest) in the period of completing education (period 1 for HS, period 2 for CD and period 3 for CG). Educational effort and labor hours are expressed as shares of discretionary time. Educational effort is endogenous in the "Fixed" allocation. Controlling for h_e means that the educational effort is taken at the exogenous level from the "Fixed allocation." Controlling for h_l means that the labor supply is chosen according to the same FOC as in "Fixed" allocation, i.e. ignoring distortions from loan repayments $\bar{\ell}_{j*}(e, w^e \varepsilon_j^e(\theta,\eta) h_l)^{ICL}$ entering the budget constraint.

the mean ability of students declines by 5% of the standard deviation. Moreover, the reform triggers increases in borrowing, as evinced by significant declines in average net worth of dropouts and graduates (see also distributions of net worth pre- and post-reform in Figure 8 in Appendix G). Relatedly, we find that 48% of workers benefit from the repayment flexibility provided by ICLs and their repayments are reduced by 44% on average.[34]

The reform's positive effects are muted by the endogeneity of agents' educational effort and labor supply after leaving college. Concerning the former, we find that while ICLs reduce the mean level of educational effort by 0.5 p.p. (or 3%), the share of college graduates increases by 0.8 p.p. To dig deeper on this, we solve for a stationary equilibrium under the reform with educational effort decisions being fixed at the baseline level. The results of this exercise in the third column of Table 6 show that the average welfare gain induced by the reform increases only by 10%($=\frac{0.90}{0.82}-1$) and that the reductions in educational effort are driven solely by new marginal enrollees of lower ability, [35] and so it is mostly generated by new entrants, and not due to distortions generated by the reform on infra-marginal agents. Furthermore, as the reform conditions repayments on current labor income, agents reduce their labor supply by 0.1 - 1.0 p.p. (depending on education level). The fourth column in Table 6 shows that controlling for both the distortions on educational effort and on labor supply increases the aggregate welfare by 24%($=\frac{1.02}{0.82}-1$).[36]

In order to investigate the interaction of ICLs with relevant general equilibrium effects, we re-calibrate a version of our model with perfect substitution between skill types (i.e. without endogenous skill premium, setting $\rho=\infty$). We find that the welfare gain associated with the ICL reform increases substantially from 0.82% up to 1.14% (see Table 7).[37] Intuitively, once the reform is introduced in the model with endogenous skill premium, its effects are accompanied by the contraction of skill premium, which similarly provides valuable indirect insurance to college enrollees and redistribution towards skilled workers. Because these general equilibrium effects also contribute to reduction of incentives for graduation, the effectiveness of the ICL reform is significantly reduced. Overall, we find that the quantitative importance of moral hazard is mild relative to the consideration of long-run general equilibrium effects operating through the skill premium.

[34] The magnitude of reductions in repayments upon introduction of ICLs is in line with the experimental evidence in [Mueller and Yannelis, 2021].

[35] In particular, the effort between columns 2 and 3 of Table 6 increases from 23.17% to 23.18% only. We confirm that the drop is driven by new marginal enrollees by solving additionally a benchmark with fixed both enrollment and effort decisions. These results are available from us upon request.

[36] Notice that the labor supply chosen upon controlling for distortions to h_l slightly differs from the "Fixed" benchmark due to selection of workers and differences in skill premia.

[37] Notice that the skill premium reported in Table 7 does change. However, this is purely due to compositional changes in workers' ability and labor supply (and not due to changes in wage rates w^U, w^S).

Statistic	Fixed	ICL
Welfare		
Average cons.-eq. welfare gain		+1.14%
↪ *Share due to the uncertainty effect*		*20%*
↪ *Share due to the level effect*		*64%*
↪ *Share due to the inequality effect*		*16%*
Average cons.-eq. welfare gain for HS		-0.16%
Average cons.-eq. welfare gain for CD		+1.76%
Average cons.-eq. welfare gain for CG		+1.57%
Education sector		
Share of college enrollees	74.7%	78.0%
Share of college graduates	32.2%	33.6%
Skill premium	90.6%	88.3%
Educational effort	22.9%	22.9%
Mean ability of enrollees	5.14	5.14
Mean parental transfer	$37,267	$37,081
Average net worth of CG	-$2,377	-$5,474
Average net worth of CD	$5,152	$3.261
Average net worth of HS	$23,658	$25,938
Borrowers qualifying for ICLs	N/A	47.8%
Mean repayment by CG	$2,131	$1,356
Mean repayment by CD	$1,006	$503
Labor income tax rate	35.2%	35.4%
Production sector		
Aggregate output	0.277	0.279
Aggregate capital	0.366	0.368
Interest rate r	5.7%	5.7%
Labor hours of CG	36.4%	35.5%
Labor hours of CD	33.2%	32.9%
Labor hours of HS	31.5%	31.3%

Table 7: Aggregate statistics of economies without and with ICLs and with perfect substitution between skill types

Note: The results come from a recalibrated economy with $\rho = \infty$. See Table 12 in Appendix G for details on parameters chosen.

Figure 3: Welfare impact of ICL reform

Note: Figure presents the welfare impact of the ICL reform on agents in period 1 at the state (a, θ) with the average value of χ realization. Assets are expressed in thousands of 2006 US Dollars.

While a lower skill premium benefits the unskilled, the increase in the labor income tax rate required to balance the government budget punishes every worker. The latter effect dominates in the case of workers with high school education, implying that the reform generates a small welfare loss to them (equivalent to a 0.19% permanent loss in consumption). Due to the contraction in the skill premium and the insurance provided, the reform generates the highest gains to college dropouts (1.73%). Analogically, the 1.13% gain of college graduates[38] is less than that of college dropouts due to the reduction in the wage rate for skilled labor, but more than that of high school graduates because of improved repayment terms of their student debt.

In order to shed more light on the heterogeneous effects of the reform, we first show in Figure 3 the distribution of welfare gains for newborns across their wealth and ability states (a, θ). We see that while the reform benefits everyone, those with the lowest-to-middle ability and medium wealth benefit from the insurance provided by ICLs the most, as these are the disadvantaged groups on the margin of enrollment.[39] Individuals with high initial wealth or ability gain significantly less as they were much more likely to graduate and faced the least difficulties with student loan repayments, even without the ICLs. Figure 4

[38] These numbers do not add up precisely to the aggregate effect of 0.82% because of the way we construct our welfare measures, as explained in the footnote below Table 6.

[39] Notice that the uniform welfare gain result in Figure 3 is at contrast with small welfare losses to high school graduates in Table 6. This is because Figure 3 averages out the college taste χ realization for each grid point. Thus, the welfare loss of high school graduates in Table 6 reflects the selection of agents with low χ.

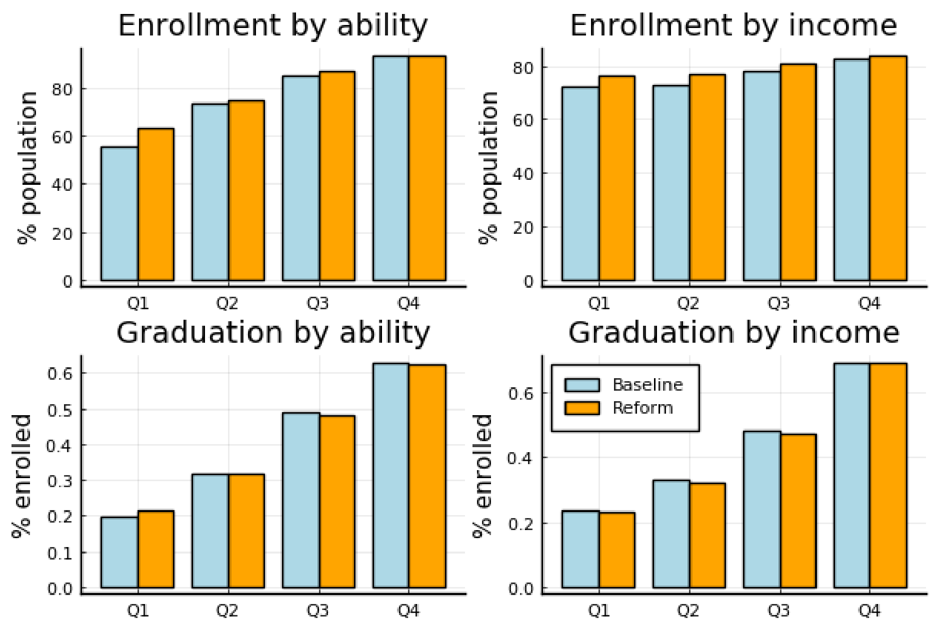

Figure 4: Enrollment and graduation rates impact of ICL reform

confirms this intuition: while enrollment strictly increase for all groups, the largest increases are concentrated among the newborns with below median ability and income. Furthermore, graduation rates of most groups decline only marginally, and increase for the least able whose enrollment response dominated the drop in educational effort.

As the ICL reform both reduces the riskiness of and subsidizes student borrowing, its welfare impact reflects the combination of these effects. Hence, we follow [Benabou, 2002] and further decompose welfare into three elements: (i) a level effect that measures the gains due to changes in the aggregate consumption, leisure, and psychic cost of college attendance; (ii) an uncertainty (or insurance) effect that measures the gains due to changes in the volatility of consumption and leisure paths across states and over time; and (iii) an inequality effect that measures the gains due to changes in the initial distribution of expected consumption, leisure and psychic cost across all the states of agents in the economy.[40] This decomposition shows that the largest part (46%) of welfare gains to newborns is indeed due to the improved insurance provided by ICLs.

Finally, due to the computational complexity of our quantitative economy, our analysis relies on a comparison of stationary distributions pre- and post-reform. While such analyses usually favor policies that lead to capital build up, this should not be a major concern in our case as the level of aggregate capital actually does not change much on impact of the reform. More importantly, our reform induces a significant 3.6 p.p. reduction in the skill

[40] In particular, we follow the decomposition described in [Abbott et al., 2019].

premium. As [Krueger and Ludwig, 2016] point out, convergence of the skill premium to its new steady state takes long time because the first affected cohorts constitute a small fraction of the overall labor force. As such, the welfare gains of college graduates in first cohorts would potentially increase as their wage rates would not decline much on impact, and the welfare of dropouts and high school graduates would decline for the exactly opposite reason.

4.2 Varying Parameters of ICLs

In this subsection, we follow with a broader analysis of the interaction between the ICL design and social welfare through two comparative statics exercises.

In our first investigation, we hold all the parameter values at the baseline calibration level, and evaluate the ICL reform while varying both the poverty threshold $\bar{y}$ and the statutory repayment rate ω (see equation (2)). We do this in a way that the expected impact of this reform on the government's budget is approximately neutral, i.e. such that the following holds:

$$\omega(y_{mean} - \bar{y}) = \omega_{US}(y_{mean} - \bar{y}_{US}) \tag{4}$$

where $\omega_{US} = 10\%$ and $\bar{y}_{US} = \$30,000$ are the parameters as in the current ICL system in the US, and y_{mean} is the weighted average before-tax labor income of individuals with discretionary income above the poverty threshold and below the maximum repayment limit.[41]

Thus, once we choose the value of $\bar{y}$, the optimal value of ω follows from the equation (4). The idea is that we change the student loan system such that the mean repayment by college enrollees is the same before and after varying the parameters of ICLs. We follow this way of balancing the (expected) government budget because the alternative of finding the exact ω balancing the (ex-post) budget constraint turns out to be not viable.[42]

Figure 5 presents the main results of varying $\bar{y}$ from \$0 up to \$35,000, with further details being relegated to Table 10 in Appendix G. Overall, we find that a high enough poverty threshold $\bar{y}$ is essential to ensuring high effectiveness of ICLs. For example, for $\bar{y} = 0$ the welfare impact of ICLs on newborns amounts to 0.50%. However, as the poverty threshold increases, we observe significant welfare gains for the newborn population, going

[41] Detailed results of this exercise in Table 10 in Appendix G show that the approximation (4) performs well as the required adjustments of the labor income tax rate to changes in $\bar{y}$ are essentially equal to 0.

[42] For a given value of $\bar{y}$, we may have multiple equilibria since balancing the government budget may be possible with multiple values of ω. This is so as ω effectively pins down incentives for exerting educational effort and graduation. Thus, for a relatively low value of ω the incentives for graduation are higher, increasing the share of high earners in the society and not requiring a high repayment rate. On the other hand, a relatively high value of ω may be an equilibrium too because it will imply a lower graduation rate calling for higher repayment rates (similarly as in the case of the Laffer curve).

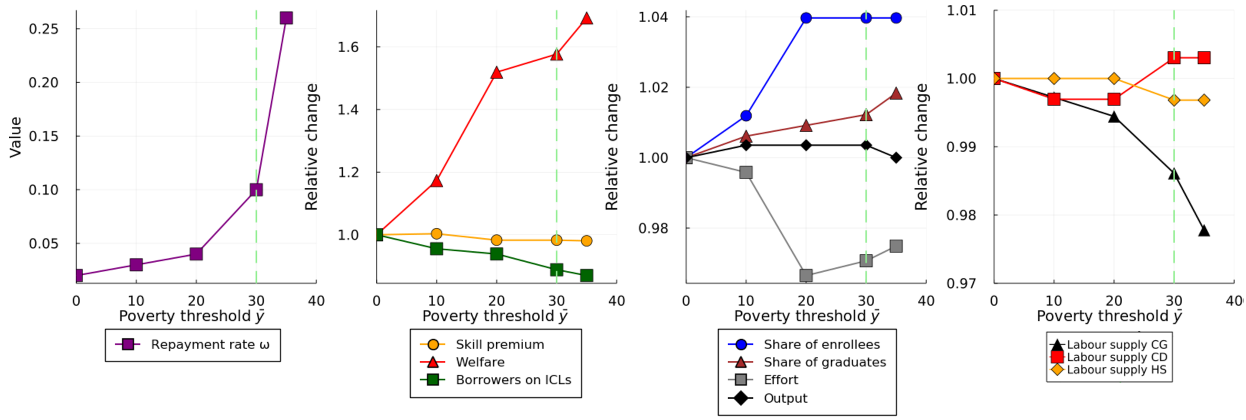

Figure 5: Economic implications of varying the repayment rate parameter ω

Note: The poverty threshold $\bar{y}$ is defined in equation (2), and is expressed in thousands of 2006 US Dollars. Apart from the first plot showing absolute values of ω, all the other statistics are expressed in relative terms to their respective value for the ICL design with $\bar{y} = 0$. The light-green vertical line indicates current policy in the US.

up to 0.88% for $\bar{y} = \$35,000$. Increases in the poverty threshold improve insurance of the downside risk, encouraging higher college enrollment (increasing by up to 4%) and borrowing (proxied through the net worth's increases of up to 40%, see Table 10 in Appendix G). Moreover, the share of borrowers qualifying for ICLs declines in $\bar{y}$ by up to 13%, because the associated increases in ω imply that indebted agents hit the repayment limit faster. From the aggregate economy perspective, this leads to reductions in the skill premium by up to 2% and a small hump-shaped response of output. Importantly, the changes in educational effort are non-monotone, reflecting the interplay of different insurance effects. For $\bar{y} \leq \$20,000$, effort declines as incentives for graduating are reduced in the degree of insurance provided. However, for higher levels of $\bar{y}$ the educational effort starts increasing as the relative value of being a graduate to the one of being a dropout is increasing.[43] Since the share of graduates is a product of both the college enrollment and educational effort, it increases by up to 2%. Finally, the labor supply of graduates decreases in the poverty threshold $\bar{y}$ as the implied increases in the repayment rate ω reduce incentives to work.

In our second investigation, we again hold all the parameters constant at the baseline calibration level and evaluate the ICL reform while varying the upper repayment limit through changes in the coefficient $\bar{\kappa}$ entering the repayments as follows:

$$\bar{\ell}_{j^*}(e, y; \bar{\kappa})^{ICL} = \begin{cases} \min\{\omega \cdot \max\{0, y - \bar{y}\}, \bar{\kappa} \cdot \bar{\ell}_{j*}(e)^F\} \text{ if } j^* \leq \bar{T} \\ 0 \text{ otherwise} \end{cases} \tag{5}$$

[43] As reflected e.g. by the convergence of debt repayments between the two groups, see Table 10 in Appendix G.

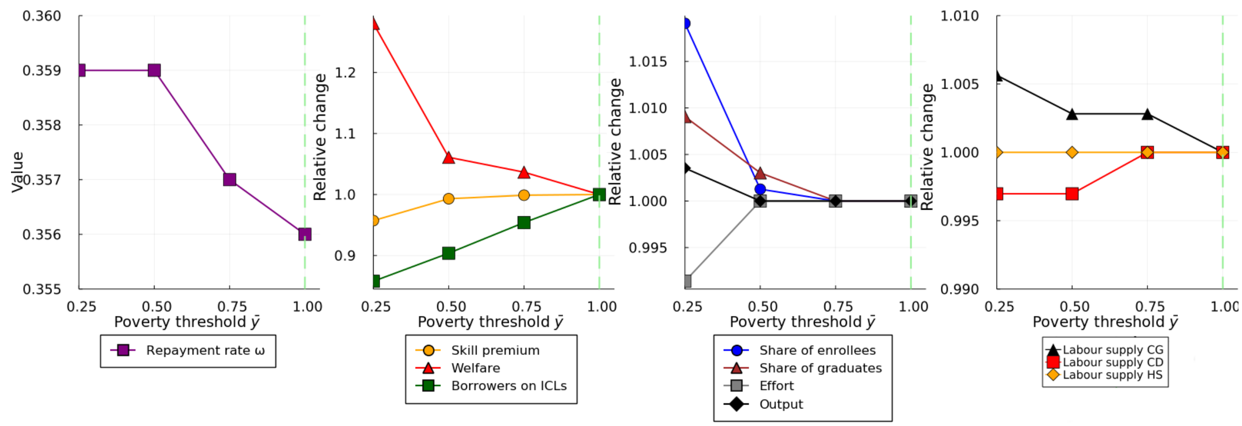

Figure 6: Economic implications of varying the repayment limit coefficient $\bar{\kappa}$

Note: Repayment limit coefficient $\bar{\kappa}$ is defined in equation (5). Apart from the first plot showing absolute values of τ_l, all the other statistics are expressed in relative terms to their respective value for the ICL design with $\bar{\kappa} = 1.0$. The light-green vertical line indicates current policy in the US.

Figure 6 shows the economic implications of varying the value of $\bar{\kappa}$ from 1.0 (as in the current ICL design) down to 0.25. As the repayment limit declines, borrowers are better protected from the upside risk of higher repayments when they are very productive. As such, this stimulates enrollment and graduation, all increasing by approx. 2% and 1% (respectively).[44] Labor supply of college graduates slightly increases as lower $\bar{\kappa}$ increases work incentives for high skilled agents. Increased skill supply implies a reduction in the aggregate skill premium, which declines from 86% by up to 4%. This effect generates additional redistribution of resources from the skilled to the unskilled, and indirectly improves consumption insurance. Notice that changes in $\bar{\kappa}$ are not self-financing, triggering an increase in the labor income tax rate of up to 0.3 p.p. Nonetheless, the consumption-equivalent welfare of newborns increases from 0.82% by up to 28% when the repayment limit is 4 times lower than the actual.

Overall, our results show that the non-linear repayment schedule of ICLs is important for enhancing its effectiveness. Increases in the poverty threshold bring the idea of providing financial aid through ICLs closer to the need-based education subsidies. Similarly, reductions of the upper repayment limit provide more incentives to productive individuals, allowing them to keep more of their earnings and so contributing to a further reduction in the costs of higher education. While targeted at workers with polar positions in the income distribution, these elements reduce the riskiness of higher education, increase its subsidization rate and ultimately lead to significant welfare improvements.

[44] Borrowing increases similarly, see details in Table 10 in Appendix G.

5 Conclusion

Higher educational attainment decisions, especially in countries where access to college is not universally provided, can be constrained by insufficient resources of young individuals and their parents. Since higher education is one of the main engines of economic growth, these constraints may be highly detrimental to modern economies' efficiency and welfare.

In this paper, we perform the social welfare analysis of ICLs in a rich life-cycle overlapping generations heterogeneous agents economy, with relevant general equilibrium effects, incomplete markets and intergenerational linkages. In particular, we explicitly account for the college dropout and income risks, and the endogeneity of educational and labor decisions that are subject to moral hazard. Combination of these elements gives rise to the traditional trade-off between incentives and insurance: stimulating higher college enrollment through ICLs reduces incentives for exerting educational effort while in college and labor supply after finishing education.

Using various sources of micro-data, we calibrate our quantitative economy to the US. Importantly, the model performs well not only in directions in which it has been calibrated but it also generates realistic graduation patterns along income quartiles, time use in college, enrollment and graduation elasticities, degree of tax progressivity, and life-cycle profiles of key economic margins.

Our analysis leads to two important conclusions. First, the current design of ICLs in the US brings a significant average welfare improvement equivalent to a 0.82% permanent increase in consumption. Intuitively, by lowering the risk associated with student debt repayments and introducing debt forgiveness, the reform stimulates higher college enrollment and graduation, benefiting most people in the economy. Interestingly, it turns out that the moral hazard induced by the reform is of a second-order importance in equilibrium. Instead, we find that the endogeneity of skill premium significantly reduces effectiveness of ICLs. Second, through two comparative statics exercises, we show that the poverty threshold and the upper repayment limit are important elements ensuring high efficiency of the ICL design. The former improves insurance of the downside risk and so improves targeting of the policy to the struggling individuals. The latter increases incentives for college attainment by ensuring that the repayments from the most productive individuals are not over-extractive.

While some elements of the ICL's design may resemble targeted subsidies, an important difference between the two is that providing financial aid through income-contingent student loans is tied to the actual labor market experiences of borrowers. Because some individuals may struggle with repayments regardless of their educational outcomes, ICLs may be much easier to implement politically. Perhaps for these reasons, the expansion in generosity of the

ICL system was an important point on Joe Biden's presidential campaign's agenda. Our results suggest that such reforms are likely to be welfare improving.

Finally, in spite of the general richness of our quantitative economy, preserving computational complexity forced us to ignore a number of important aspects that might influence evaluation of student loan programs. For instance, our quantitative model entailed a single college charging a fixed tuition fee. To this end, it could be interesting to introduce a heterogeneous and competitive market for colleges (as in [Cai and Heathcote, 2018]) to study the impact of increasing the generosity of student loans (through e.g. introduction of ICLs) on equilibrium college pricing.

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Appendices

A Simple Model

In what follows, we introduce our two-period model and use it to characterize both the laissez-faire equilibrium and constrained second best allocation. We show that ICLs can implement the latter allocation, and show that this policy increases college enrollment at the cost of reducing educational effort.

A.1 Environment

Our partial equilibrium economy runs for two periods and has a unit mass of ex-ante heterogeneous agents. They are born in period 1 with an inherent college taste χ drawn from a uniform distribution F with support on the (a, b) interval. Given their college taste, they make a decision about enrolling into college. We assume that every agent starts their life with no assets. In order to attend college, they need to borrow using student loan system to pay tuition φ. Borrowing is subject to the exogenously given interest rate r. Furthermore, college education is risky and in order to increase their chances of a graduation, agents need to exert educational effort h_e associated with disutility $v(h_e)$, which is twice continuously differentiable and satisfies $v'(h_e)\,,\ v''(h_e) > 0$ and $v'(h_e)_{|h_e=0} = 0$. Consequently, they become college graduates and dropouts with endogenous probabilities $p(h_e)$ and $1 - p(h_e)$, where the graduation probability function is twice continuously differentiable and satisfies $p(0) = 0,\ p'(h_e),\ -p''(h_e) > 0$.

The college graduation shock realizes at the beginning of period 2. The wage income of agents is as follows:

$$w_e = \begin{cases} w_{CG} & \text{with } p(h_e), \text{ if enrolled} \\ w_{CD} & \text{with } 1 - p(h_e), \text{ if enrolled} \\ w_{HS} & \text{if not enrolled} \end{cases}$$

where the productivity parameters $w_{CG} > w_{CD} > w_{HS}$ are exogenously given.

This income is used for financing consumption (which takes place only in period 2) and, if agents enrolled into college, to repay their student debt together with the interest. Agents value their consumption according to the utility function $u(c)$ satisfying $u'(c),\ -u''(c) > 0$. Assuming that the discount rate equals 1, each agent with college taste χ maximizes her expected utility given by:

$$\max\left\{u(c_{HS}), \max_{h_e} p(h_e)u(c_{CG}) + (1 - p(h_e))u(c_{CD}) - v(h_e) + \chi\right\} \tag{6}$$

subject to budget constraint of:

$$c_e + (1 + r)\,\varphi \cdot \mathbf{1}_{e\in\{CD,CG\}} \leq w_e \ \forall e \in \{HS, CD, CG\} \tag{7}$$

where $\mathbf{1}_{e\in\{CD,CG\}}$ is the indicator function taking value equal to 1 if the agent enrolls into college.

The setup implicitly assumes that the borrowing constraints are such that agents can always cover their tuition fee φ. We do not allow workers to default on their student loans. This assumption is in line with the current institutional setup in the US where bankruptcies on student loans cannot be discharged under Chapter 13, unlike most of consumer bankruptcies which are dischargeable under Chapter 7.

Finally, notice that agents do not have access to any state-contingent claims that would allow them to hedge the college dropout risk.

A.2 Laissez Faire Equilibrium

The laissez faire (LF) competitive equilibrium is a list of optimal enrollment and educational effort decisions maximizing (6) subject to (7). Since the problem is concave, the ensuing equilibrium is unique.

Agents will enroll if their inherent college taste χ is sufficiently high, satisfying:

$$\chi \geq \bar{\chi} \equiv u\left(c_{HS}^{LF}\right) - \left[p(h_e^{LF})u\left(c_{CG}^{LF}\right) + (1 - p(h_e^{LF}))u\left(c_{CD}^{LF}\right) - v(h_e^{LF})\right] \tag{8}$$

We focus on interior solutions by making the following assumption:

Assumption 1. Given all the other parameters, the cost of attending college φ is such that in all allocations considered the mass of agents enrolling is interior, i.e. $\Phi = \frac{\bar{\chi}-a}{b-a} \in (0,1)$.

The equilibrium choice of effort is characterized by the following first order condition:

$$v'\left(h_e^{LF}\right) = p'\left(h_e^{LF}\right)\left(u\left(c_{CG}^{LF}\right) - u\left(c_{CD}^{LF}\right)\right) \tag{9}$$

This optimality condition equalizes the marginal cost of educational investment with the expected marginal benefit. Since the graduation probability is a continuous, monotone and concave function and the college taste does not affect the values of graduating or dropping out, every enrolled student chooses the same level of equilibrium effort h_e.

A.3 Constrained Second Best and ICLs

We move on to characterizing the allocation where planner has to account for the incentive compatibility constraints on enrollment and educational effort and can redistribute resources across dropouts and graduates, but not between enrollees and non-enrollees. In other words, we proceed with the "constrained" second best analysis. We explicitly include this constraint since we want to understand the pure effect of insurance against the dropout risk on enrollment, effort and consumption. Then, we discuss its decentralization with a system of ICLs, and ultimately we investigate their impact on enrollment and graduation.

The planning problem reads:

Problem 1. *The constrained second best (SB') allocation is a solution to:*

$$\max_{\bar{\chi}, h_e^{SB'}, c_{CD}^{SB'}, c_{CG}^{SB'}} \int_a^{\bar{\chi}} u\left(w_{HS}\right) \mathrm{d}F + \int_{\bar{\chi}}^{b} \left[p(h_e^{SB'})u\left(c_{CG}^{SB'}\right) + (1-p(h_e^{SB'}))u\left(c_{CD}^{SB'}\right) - v\left(h_e^{SB'}\right) + \chi\right] \mathrm{d}F$$

subject to:

$$(\mu)\ \ p\left(h_e^{SB'}\right)\left(c_{CG}^{SB'} - w_{CG}\right) + \left(1 - p\left(h_e^{SB'}\right)\right)\left(c_{CD}^{SB'} - w_{CD}\right) + (1+r)\varphi \le 0 \tag{10}$$

$$(\psi_e)\ \ h_e^{SB'} = \text{argmax}_{\tilde{h}_e}\{p\left(\tilde{h}_e\right)u\left(c_{CG}^{SB'}\right) + \left(1 - p\left(\tilde{h}_e\right)\right)u\left(c_{CD}^{SB'}\right) - v\left(\tilde{h}_e\right)\} \tag{11}$$

$$(\psi_\Phi)\ \ \bar{\chi} = u\left(w_{HS}\right) - \left[p(h_e)u\left(c_{CG}^{SB'}\right) + (1-p(h_e))u\left(c_{CD}^{SB'}\right) - v(h_e^{SB'})\right] \tag{12}$$

It is well understood that the third constraint corresponds to a continuum of inequality constraints [Rogerson, 1985]. However, if Problem 1 is concave, we can replace it by a necessary and sufficient first order condition:[45]

$$v'\left(h_e^{SB'}\right) = p'\left(h_e^{SB'}\right)\left(u\left(c_{CG}^{SB'}\right) - u\left(c_{CD}^{SB'}\right)\right) \tag{13}$$

The condition (13) holds with equality due to our assumptions of $v'(h_e)_{|h_e=0} = 0$ and the effort disutility and probability functions being convex and concave (respectively). Furthermore, the latter two assumptions deliver sufficiency of (13) since:

$$-v''\left(h_e^{SB'}\right) + p''\left(h_e^{SB'}\right)\left(u\left(c_{CG}^{SB'}\right) - u\left(c_{CD}^{SB'}\right)\right) < 0 \; \forall h_e^{SB'} \tag{14}$$

The following lemma derives the FOCs characterizing this allocation:

Lemma 1. *The constrained second best allocation is characterized by the following first order conditions:*

$$c_{CD}^{SB'}: \; u'\left(c_{CD}^{SB'}\right)\left[\left(1-p\left(h_e^{SB'}\right)\right)\left((1-\Phi)+\psi_\Phi\right) - \psi_e p'\left(h_e^{SB'}\right)\right] = \mu\left(1-\Phi\right)\left(1-p\left(h_e^{SB'}\right)\right) \tag{15}$$

$$c_{CG}^{SB'}: \; u'\left(c_{CG}^{SB'}\right)\left[p\left(h_e^{SB'}\right)\left((1-\Phi)+\psi_\Phi\right) + \psi_e p'\left(h_e^{SB'}\right)\right] = \mu\left(1-\Phi\right)p\left(h_e^{SB'}\right) \tag{16}$$

$$h_e^{SB'}: \; \mu\left(1-\Phi\right)p'\left(h_e^{SB'}\right)\boldsymbol{\Delta}_{graduate} = \psi_e\left\{v''\left(h_e^{SB'}\right) - p''\left(h_e^{SB'}\right)\left(u\left(c_{CG}^{SB'}\right) - u\left(c_{CD}^{SB'}\right)\right)\right\} \tag{17}$$

$$\Phi: \; \mu\boldsymbol{\Delta}_{enroll} = \psi_\Phi(b-a) \tag{18}$$

where:
$\Delta_{graduate} = (w_{CG} - c_{CG}^{SB'}) - (w_{CD} - c_{CD}^{SB'})$
$\Delta_{enroll} = \left[p\left(h_e^{SB'}\right)\left(w_{CG} - c_{CG}^{SB'}\right) + \left(1-p\left(h_e^{SB'}\right)\right)\left(w_{CD} - c_{CD}^{SB'}\right) - (1+r)\varphi\right]$
$\Phi = \frac{\bar{\chi}-a}{b-a}$

with Φ denoting the enrollment rate, and ψ_Φ, ψ_e and μ denoting the Lagrange multipliers on the following constraints: enrollment (12), incentive compatibility (13) and resource for enrollees (10), respectively.

[45] See [Abraham et al., 2011] for more on the first order approach in problems with moral hazard.

Proof. First, notice that the objective function is equivalent to:

$$\max_{h_e^{SB'},\Phi,c_{CD}^{SB'},c_{CG}^{SB'}} \left\{ \Phi u\left(w_{HS}\right) + (1-\Phi)\left[p(h_e^{SB'})u\left(c_{CG}^{SB'}\right) + (1-p(h_e^{SB'}))u\left(c_{CD}^{SB'}\right) - v\left(h_e^{SB'}\right)\right] \right.$$
$$\left. + \frac{b^2 - ((b-a)\Phi + a)^2}{2(b-a)} \right\}$$

where $\Phi = \frac{\bar{\chi}-a}{b-a}$.

The consumption first order condition follows immediately. The effort first order condition follows from:

$$\begin{aligned}(1-\Phi)\left(p'(h_e)\left(u'(c_{CG}) - u'(c_{CD})\right) - v'(h_e)\right) - \mu\left(1-\Phi\right)p'(h_e)\left(c_{CG} - c_{CD} - w_{CG} + w_{CD}\right)\\ -\psi_e\left(v''(h_e) - p''(h_e)\left(u'(c_{CG}) - u'(c_{CD})\right)\right) - \psi_\Phi\left(-p'(h_e)\left(u'(c_{CG}) - u'(c_{CD})\right) + v'(h_e)\right) = 0\end{aligned}$$

after applying the effort incentive compatibility constraint (13) and rearranging terms.

The enrollment first order condition follows from:

$$\begin{aligned}u\left(w_{HS}\right) - \left(p(h_e)u(c_{CG}) + (1-p(h_e))u(c_{CD}) - v(h_e)\right) - \left((b-a)\Phi + a\right) + \psi_\Phi\left(b-a\right)\\ +\mu\left(p(h_e)(c_{CG} - w_{CG}) + (1-p(h_e))(c_{CD} - w_{CD})\right) = 0\end{aligned}$$

after applying the enrollment constraint (12) and rearranging terms. □

As the above allocation relies on a direct assignment of consumption and incentive-compatible enrollment and effort levels by the benevolent planner, it tells us little about optimal policy interventions. Thus, we now explore a way of implementing this allocation as a decentralized competitive equilibrium with income-contingent debt repayment rates $\varphi_{CD}, \varphi_{CG}$. While the objective function of agents is the same as (6) in the laissez faire equilibrium, the budget constraints take the following form:

$$c_{HS}^{dec} \leq w_{HS} \tag{19}$$

$$c_e^{dec} + (1+r)\,\varphi_e \leq w_e \text{ if } e \in \{CD, CG\} \tag{20}$$

where c_e^{dec} is a consumption of an agent with education level e in a decentralized equilibrium. Furthermore, the enrollment and effort decisions are governed by equivalents of (8) and (9).

Given these, we can implement the constrained second best allocation as follows:

Proposition 1. *There exist policy instruments φ_{CD} and φ_{CG} implementing as a competitive equilibrium the constrained second best allocation SB'. Furthermore, in this competitive equilibrium it holds that:*

1. *The repayment rates provide partial insurance against dropout risk, i.e. $\varphi_{CD} < \varphi_{CG}$ and $c_{CD} < c_{CG}$.*
2. *The enrollment rate is higher than in the laissez faire equilibrium, i.e. $1 - \Phi^{SB'} > 1 - \Phi^{LF}$.*
3. *The educational effort is lower than in the laissez faire equilibrium, i.e. $h_e^{SB'} < h_e^{LF}$.*

Proof. The optimal repayment and tax rates can be found by equating:

$$c_{CD}^{SB'} \stackrel{!}{=} c_{CD}^{dec} = w_{CD} - (1+r)\,\varphi_{CD}$$
$$c_{CG}^{SB'} \stackrel{!}{=} c_{CG}^{dec} = w_{CG} - (1+r)\,\varphi_{CG}$$

where $c_e^{SB'}$, $i \in \{CD, CG\}$ jointly solve the system of consumption first order conditions in Lemma 1. Since effort chosen is according to the same first order condition in both the constrained second best and ICL allocations, we automatically have that $h_e^{SB'} = h_e^{dec}$, and as a consequence $\bar{\chi}^{SB'} = \bar{\chi}^{dec}$.

Then, in order to prove the first claim, we first show that the amount of insurance provided is positive, i.e. that $c_{CG}^{SB'} - w_{CG} < c_{CD}^{SB'} - w_{CD}$. Assume otherwise: $c_{CG}^{SB'} - w_{CG} \geq c_{CD}^{SB'} - w_{CD}$. Because $w_{CG} > w_{CD}$, this implies that $c_{CG}^{SB'} > c_{CD}^{SB'}$. Given the inequality (14), it follows that $\Delta_{graduate} < 0$ and so we infer from the effort first order condition (17) that it must be that $\psi_e \leq 0$. If $\psi_e = 0$, then $c_{CG}^{SB'} = c_{CD}^{SB'}$ from the consumption FOCs (15)-(16). If $\psi_e < 0$, combining FOCs (15)-(16) delivers:

$$\frac{u'\left(c_{CD}^{SB'}\right)}{u'\left(c_{CG}^{SB'}\right)} \cdot \frac{\left(1-p\left(h_e^{SB'}\right)\right)\left[1-\Phi+\psi_\Phi-\psi_e p'\left(h_e^{SB'}\right)\right]}{p\left(h_e^{SB'}\right)\left[1-\Phi+\psi_\Phi+\psi_e p'\left(h_e^{SB'}\right)\right]} = \frac{1-p\left(h_e^{SB'}\right)}{p\left(h_e^{SB'}\right)}$$

$$(use\ \psi_e < 0) \Rightarrow$$

$$\frac{u'\left(c_{CD}^{SB'}\right)}{u'\left(c_{CG}^{SB'}\right)} \cdot \frac{\left(1-p\left(h_e^{SB'}\right)\right)\left[1-\Phi+\psi_\Phi\right]}{p\left(h_e^{SB'}\right)\left[1-\Phi+\psi_\Phi\right]} < \frac{1-p\left(h_e^{SB'}\right)}{p\left(h_e^{SB'}\right)}$$

$$\Longleftrightarrow$$

$$u'\left(c_{CD}^{SB'}\right) < u'\left(c_{CG}^{SB'}\right)$$

$$\Longleftrightarrow$$

$$c_{CD}^{SB'} > c_{CG}^{SB'}$$

In both cases a contradiction.

We now show that the amount of insurance provided is not full, i.e. that $c_{CD}^{SB'} < c_{CG}^{SB'}$. Assume otherwise. Then, from the incentive compatibility constraint (13), $h_e = 0$ and $p(h_e) = 0$. From the first order condition on $c_{CG}^{SB'}$, we get that $\psi_e = 0$. From the first order condition for e, it must be that either (i) $\Delta_{graduate} = 0$, (ii) $\mu = 0$, or (iii) $\Phi = 1$. In case (i), we have that $0 < w_{CG} - w_{CD} = c_{CG} - c_{CD}$, a contradiction. In case (ii), from the first order condition for Φ we get that $\psi_\Phi = 0$. Thus, the first order condition for c_{CD} implies that $u'(c_{CD})(1-\Phi) = 0$, and so that no one enrolls, i.e. $\Phi = 1$. Notice that this is the same as the condition of the case (iii). No enrollment implies that the social welfare amounts to $u(w_{HS})$. However, by Assumption 1, the enrollment in competitive equilibrium is strictly positive, i.e. $\Phi \in (0,1)$. Because of this, some people in competitive equilibrium will enjoy a utility level strictly higher than $u(w_{HS})$. Thus, $c_{CD}^{SB'} \geq c_{CG}^{SB'}$ implies that the overall social welfare is strictly higher in the competitive equilibrium than in the second best. This leads to a contradiction because the competitive equilibrium allocation lies within the constraint set of the second best problem.

For the second claim, define first $V^{enroll,LF} \equiv \left[p(h_e^{LF})u\left(c_{CG}^{LF}\right) + (1-p(h_e^{LF}))u\left(c_{CD}^{LF}\right) - v\left(h_e^{LF}\right)\right]$ and $V^{enroll,SB'} \equiv \left[p(h_e^{SB'})u\left(c_{CG}^{SB'}\right) + (1-p(h_e^{SB'}))u\left(c_{CD}^{SB'}\right) - v\left(h_e^{SB'}\right)\right]$. Then, assume the opposite, i.e. that $\Phi^{LF} \leq \Phi^{SB'}$. This implies that $V^{enroll,LF} \geq V^{enroll,SB'}$. Because of this, it follows that $\Phi^{LF} \leq \Phi^{SB'}$, and (by definition) $\bar{\chi}^{LF} \leq \bar{\chi}^{SB'}$. Consider now the following cases:

1. Agents with $\chi < \bar{\chi}^{LF}$ do not enroll in any case, so they do not experience any change in welfare $u\left(c_{HS}^{LF}\right) = u\left(c_{HS}^{SB'}\right)$.

2. Agents with $\chi \in \left[\bar{\chi}^{LF}, \bar{\chi}^{SB'}\right]$ used to enroll in LF and in SB' do not anymore, so their welfare loss amounts to $\mathrm{E}\left(u(c^{LF}|enroll)\right) - v\left(h_e^{LF}\right) + \chi - u\left(c_{HS}^{SB'}\right) \geq 0$ because

$$\mathrm{E}\left(u(c^{LF}|enroll)\right) - v\left(h_e^{LF}\right) + \chi \geq u\left(c_{HS}^{LF}\right) = u\left(c_{HS}^{SB'}\right).$$

3. Agents with $\chi > \bar{\chi}^{SB'}$ enroll in both cases and so their welfare loss amounts to $V^{enroll,LF} - V^{enroll,SB'} \geq 0$.

Thus, agents are weakly worse off under SB'. Furthermore, notice that because the constraint set of SB' is a superset of the constraint set in LF, everything that is achievable in LF is achievable in SB'. Because SB' is characterized by partial insurance, it follows that the SB' allocation is different than the LF one. In particular, because we have that $c_{CD}^{SB'} > w_{CD}$, it follows that the SB' allocation is not attainable under LF. Thus, SB' achieves higher social welfare, leading to a contradiction.

For the third claim, notice that the fact of SB' being characterized by partial insurance implies that $c_{CG}^{SB'} < c_{CG}^{LF}$ and $c_{CD}^{SB'} > c_{CD}^{LF}$. Together with the effort incentive compatibility constraint (13), this implies that $h_e^{SB'} < h_e^{LF}$. □

Intuitively, the uninsurable nature of college dropout risk limits college enrollment of risk averse agents. To address this issue, the optimal design of ICLs overcomes the market incompleteness and provides insurance against the dropout risk, stimulating higher enrollment in equilibrium. However, this insurance is only partial because of the trade-off implied by moral hazard: the better is the insurance, the lower are the incentives for providing educational effort. In particular, the planner cannot implement full insurance equating consumption of dropouts and graduates, as agents would provide no effort and so no one would graduate.

B Stationary Equilibrium

Let $\boldsymbol{s}_j^c \in S_j^c$ be the age-specific state vector for college enrollees and $\boldsymbol{s}_j \in S_j$ for workers and retirees. We also define the age-specific state vector for workers and retirees conditional on education e as $\boldsymbol{s}_j^e \in S_j^e$.

Definition 1. *A stationary equilibrium is a list of value functions of workers and college enrollees $V_j(\boldsymbol{s}_j)$, $V_j^c(\boldsymbol{s}^c)$; decision rules of enrollment $d_j(\boldsymbol{s}_1^c)$; decision rules of consumption, asset holdings, labor hours, output, and parental transfers of workers $c_j(\boldsymbol{s}_j)$, $a_j'(\boldsymbol{s}_j)$, $h_{\ell,j}(\boldsymbol{s}_j)$, $b(\boldsymbol{s}_j)$; decision rules of college enrollees $c_j^c(\boldsymbol{s}_j^c)$, $a_j'^c(\boldsymbol{s}_j^c)$, $h_{\ell,j}^c(\boldsymbol{s}_j^c)$, $h_{e,j}^c(\boldsymbol{s}_j^c)$; capital, and labor inputs K, H^S, H^U; prices r, w^S, w^U; policy τ_l; and measures $\boldsymbol{\mu} = \{\mu_j^c(\boldsymbol{s}^c), \mu_j(\boldsymbol{s}_j), \mu_j^e(\boldsymbol{s}_j^e)\}$ such that*

1. *Taking prices and policy as given, value functions* $V_j(\boldsymbol{s}_j)$, $V^c(\boldsymbol{s}^c)$ *solve the individual Bellman equations and* $c_j(\boldsymbol{s}_j)$, $a'_j(\boldsymbol{s}_j)$, $h_{\ell,j}(\boldsymbol{s}_j)$, $b(\boldsymbol{s}_j)$, $c^c_j(\boldsymbol{s}^c_j)$, $a'^c_j(\boldsymbol{s}^c_j)$, $h^c_{\ell,j}(\boldsymbol{s}^c_j)$, $h^c_{e,j}(\boldsymbol{s}^c_j)$, $d_j(\boldsymbol{s}^c_1)$ *are associated decision rules.*

2. *Taking prices and policy as given,* K, H^S, H^U *solve the optimization problem of the firm.*

3. *The government budget is balanced.*

$$G_c + G_e + \sum_{j=j_r}^{J} \int_{S_j} P(e,\theta) d\mu_j = \int_{S^c} T(c^c(\boldsymbol{s}^c_j), a^c(\boldsymbol{s}^c_j), y^c(\boldsymbol{s}^c_j)) d\mu^c$$
$$+ \sum_j \int_{S_j} T(c_j(\boldsymbol{s}_j), a_j(\boldsymbol{s}_j), y_j(\boldsymbol{s}_j)) d\mu_j$$

where

$$G_c = gF(K,H)$$
$$G_e = \sum_{j=1}^{2} \int_{S^c_j} (s + 0.5\underline{A}^c) d\mu^c_j - \sum_j \int_{S_j} \bar{\ell}^*_j d\mu_j.$$

and

$$y_j(\boldsymbol{s}_j) = w^e \epsilon^e_j(\theta,\eta) h_{\ell,j}(\boldsymbol{s}_j)$$
$$y^c(\boldsymbol{s}^c) = w^U \epsilon^U_1(\theta,\eta) h^c_{\ell,j}(\boldsymbol{s}^c_j)$$

4. *Labor and asset markets clear.*

$$H^S = \sum_{j=2}^{j_r-1} \int_{S^{CG}_j} \epsilon^{CG}_j(\theta,\eta) h_{l,j}(\boldsymbol{s}_j) d\mu^{CG}_j$$

$$H^U = \sum_{j=2}^{j_r-1} \int_{S^{CD}_j} \epsilon^{CD}_j(\theta,\eta) h_{l,j}(\boldsymbol{s}_j) d\mu^{CD}_j$$
$$+ \sum_{j=1}^{j_r-1} \int_{S^{HS}_j} \epsilon^{HS}_j(\theta,\eta) h_{l,j}(\boldsymbol{s}_j) d\mu^{HS}_j + \int_{S^c_1} \epsilon^{HS}_1(\theta,\eta) h^c_{l,1}(\boldsymbol{s}^c_1) d\mu^c_1 + \int_{S^c_2} \epsilon^{CD}_1(\theta,\eta) h^c_{l,2}(\boldsymbol{s}^c_2) d\mu^c_2$$

and

$$K = \sum_{j=1}^{J} \int_{S_j} a'_j(\boldsymbol{s}_j) d\mu_j + \sum_{j=1}^{2} \int_{S^c_j} a'^c(\boldsymbol{s}^c_j) d\mu^c_j$$

5. *Measures $\boldsymbol{\mu}$ are reproduced for each period: $\boldsymbol{\mu}(S) = Q(S, \boldsymbol{\mu})$ where $Q(S, \cdot)$ is a transition function generated by decision rules and exogenous laws of motion, and S is the generic subset of the Borel-sigma algebra defined over the state space.*

C Computation of Stationary Equilibrium

This section describes the method of computing an equilibrium.

1. Starting from an initial vector of aggregate variables $\boldsymbol{w} = \left(r, w^S, w^U, \tau_l\right)$, compute pension $P(e; \theta)$ required for individual decision problems.

2. Given these variables, solve individuals' decision problems. This step consists of substeps.

   (a) Solve backward the Bellman equations for age $j = J, \ldots, j_b + 1$. The number of grids for assets is 30. The number of grids for college taste is 30. We apply the endogenous grid method.

   (b) Given an initial guess of the value function of newborns V^0, solve backward the individual problems from $j = j_b, \ldots, 1$ for value functions and policy functions. This leads to a new V_0.

   (c) Given the converged V_0, solve the decision rules of individuals until convergence.

3. Interpolate linearly assets to 80.

4. Starting from an initial measure μ_0 and given decision rules, solve forward from μ_0 to μ_J and update μ_0 until convergence.

5. Given the measures, derive the new aggregate variables K, H^S, H^U, and τ_l from the government budget constraint. Compute the new prices from the first order conditions of the representative firm and go back to step 2.

D Pension

In modeling the retirement benefits, we follow [Krueger and Ludwig, 2016]. In our economy, the average life-time income is given by:

$$\hat{y}(e, \theta) = \frac{\sum_{j=2}^{j_r - 1} w^e \varepsilon_j^e(\theta, 1) \times 0.333}{j_r - 2}.$$

.

Given the latter, the pension formula is given by:

$$P(e,\theta) = \begin{cases} s_1\hat{y}(e,\theta) & \text{for } \hat{y}(e,\theta) \in [0, b_1) \\ s_1 b_1 + s_2(\hat{y}(e,\theta) - b_1) & \text{for } \hat{y}(e,\theta) \in [b_1, b_2) \\ s_1 b_1 + s_2(b_2 - b_1) + s_3(\hat{y}(e,\theta) - b_2) & \text{for } \hat{y}(e,\theta) \in [b_2, b_3) \\ s_1 b_1 + s_2(b_2 - b_1) + s_3(b_3 - b_2) & \text{for } \hat{y}(e,\theta) \in [b_3, \infty) \end{cases}$$

where $s_1 = 0.9$, $s_2 = 0.32$, $s_3 = 0.15$, $b_1 = 0.20\tilde{y}$, $b_2 = 1.23\tilde{y}$, $b_3 = 2.18\tilde{y}$, and $\tilde{y} = \$38,651$ annually.

E Labor Productivity Process

Our approach for estimating the labor productivity process is in line with methods usually employed in the literature, e.g. in [Abbott et al., 2019]. First, in order to identify the effect of age on wages, we use the 1968-2014 waves of the Panel Study of Income Dynamics (PSID).[46] We use the data on 11,512 individuals with age between 25 and 63 in the SRC sample of household heads. Furthermore, (i) we drop people with less than 8 years of observations, (ii) we restrict the sample to individuals with positive hours supplied, and (iii) we drop people reporting extreme changes in hourly wages (changes in log earnings larger than 4 or less than -2) or extreme hourly wages (less than \$1 or larger than \$400). This leaves us with a sample of 3,518 household heads.

Then, we define education groups as follows. High school graduates are those with 12 years of education completed, college dropouts - between 13 and 15, and college graduates - at least 16. Given this, we regress log hourly wages on education-specific quadratic age polynomials with year dummies. Results of this exercise are in Table 8. Using these results, we compute predicted productivity at each age for individuals in each education group, take average of these over periods of 4 years (equal to the model's periodicity), and then we match these estimates with the ones implied by our quantitative model.[47]

For the law of motion of residuals η, we use the residuals of the regression for the age profile from the same PSID sample. For the purpose of calibration, we assume that job experience amounts to age minus 18 for high school graduates, age minus 20 for college dropouts, and age minus 22 for college graduates. Assuming that there is an i.i.d. measurement error and an individual fixed effect, we apply a minimum distance estimator (see e.g. [Chamber-

[46] From 1997, the PSID has become biannual.

[47] We normalize the process so that productivity at the first period after the education stage is unity.

	High school graduates	College dropouts	College graduates
Age	.0530181	.0684129	.0955783
	(.0030501)	(.0040353)	(.0036997)
Age^2	-.0005314	-.0006872	-.0009521
	(.0000356)	(.0000474)	(.0000429)

Table 8: Age profile estimates of each education level

Note: Standard errors in parenthesis. The methodology is explained in Appendix E.

lain, 1984]) on moments including covariances of residuals at different age-lags (for age 25 to 39). This procedure gives us estimates of persistence ρ^e, the variance of the residual σ_η^e, the variance of the fixed effect, and the variance of the measurement error for each education level.

To identify the effect of ability on wages ϵ_θ^e, we use the NLSY79 sample of 11,878 people. After restricting it to observations with positive hours, and to individuals with at least 8 years of observations, not enrolled into college, between 25 and 63 years old, and not reporting extreme changes in hourly wages (changes in log earnings larger than 4 or less than -2) or extreme hourly wages (less than \$1 or larger than \$400), we are left with 3,476 people in our sample. Furthermore, we (i) filter out the age effect estimated above using the PSID, and (ii) approximate ability with the log of the AFQT80 raw score. We obtain our estimates by regressing hourly wages on ability for each education level (HS, CD, and CG) and controlling for the year fixed effects. See Table 1 for results of this exercise.

F Intergenerational Ability Transmission

We estimate the transmission of ability from parents to children using data from the National Longitudinal Survey of Youth. In particular, we approximate (i) parents' ability using data from the NLSY79, and (ii) ability of children using data from the "NLSY79 Child & Young Adult." The sample consists of 11,521 children born to 4,934 female respondents.

The "NLSY79 Child & Young Adult" is a bi-annual survey started in 1986 and it provides information on the PIAT math, the PIAT reading recognition and the PIAT reading comprehension test scores of the children of the NLSY79 women. Because we focus on cognitive ability, we approximate the high school ability of children using the PIAT math score.[48] We exclude children with missing PIAT math scores, leaving us with 9,232 children born to

[48] In particular, we use the standardized PIAT math score, which adjusts for different ages at which the test is taken and is comparable across age. If there are multiple PIAT math scores for a child, we use only the latest score.

parents/children	Ability Q1	Ability Q2	Ability Q3	Ability Q4
Ability Q1	0.4760	0.3011	0.1565	0.0663
Ability Q2	0.2824	0.3068	0.2547	0.1561
Ability Q3	0.1717	0.2571	0.3167	0.2544
Ability Q4	0.0942	0.1658	0.2978	0.4423

Table 9: Intergenerational ability transmission Markov chain

Note: Ability levels correspond to quartiles of ability distribution in NLSY79, as measured by PIAT and AFQT test scores.

4,055 mothers.

Finally, we proxy mothers' ability using AFQT scores. Because of this, we only use respondents whose both AFQT scores and education levels are recorded. As we focus on people with at least a high school degree, this leaves us with 6,193 children born to 2,828 mothers.

G Additional Figures and Tables

Statistic	$\bar{y} = \$0$	$\bar{y} = \$10$	$\bar{y} = \$20$	$\bar{y} = \$30$	$\bar{y} = \$35$
Repayment rate ω	2%	3%	4%	10%	26%
Welfare					
Average cons.-eq. welfare gain	+0.50%	+0.61%	0.79%	+0.82%	+0.88%
↪ *Share due to the uncertainty effect*	*96%*	*60%*	*38%*	*46%*	*37%*
↪ *Share due to the level effect*	*-10%*	*13%*	*49%*	*42%*	*50%*
↪ *Share due to the inequality effect*	*14%*	*27%*	*13%*	*12%*	*13%*
Average cons.-eq. welfare gain for HS	-0.16%	-0.19%	-0.14%	-0.19%	-0.19 %
Average cons.-eq. welfare gain for CD	+1.00%	+1.26%	+1.66%	+1.73%	+1.73%
Average cons.-eq. welfare gain for CG	+1.04%	+1.07%	+1.04%	+1.14%	+1.43%
Education sector					
Share of college enrollees	75.6%	76.5%	78.6%	78.6%	78.6%
Share of college graduates	32.7%	32.9%	33.0%	33.1%	33.3%
Skill premium	87.9%	88.2%	86.4%	86.4%	86.2%
Educational effort	23.9%	23.8%	23.1%	23.2%	23.3%
Mean ability of enrollees	5.145	5.145	5.139	5.139	5.139
Mean parental transfer	\$36,243	\$36,233	\$36,026	\$36,025	\$35,638
Average net worth of CG	-\$5,403	-\$5,558	-\$5,901	-\$6,138	-\$7,691
Average net worth of CD	\$3,777	\$3,628	\$3,091	\$2,961	\$2,748
Average net worth of HS	\$23,507	\$23,741	\$25,606	\$25,618	\$25,533
Borrowers qualifying for ICLs	53.8%	51.4%	50.5%	47.8%	46.8%
Mean repayment by CG	\$1,436	\$1,444	\$1,422	\$1,355	\$1,244
Mean repayment by CD	\$714	\$640	\$538	\$507	\$507
Labor income tax rate	35.6%	35.6%	35.6%	35.6%	35.7%
Production sector					
Aggregate output	0.282	0.283	0.283	0.283	0.282
Aggregate capital	0.369	0.370	0.370	0.370	0.369
Interest rate r	5.8%	5.8%	5.8%	5.8%	5.8%
Labor hours of CG	36.0%	35.9%	35.8%	35.5%	35.2%
Labor hours of CD	32.9%	32.8%	32.8%	33.0%	33.0%
Labor hours of HS	31.6%	31.6%	31.6%	31.5%	31.5%

Table 10: Aggregate statistics of economies with ICLs and different poverty thresholds

Statistic	$\bar{\kappa}$=0.25	$\bar{\kappa}$=0.50	$\bar{\kappa}$=0.75	$\bar{\kappa}$=1.0
Welfare				
Average cons.-eq. welfare gain	+1.05%	+0.87%	0.85%	+0.82%
$\hookrightarrow$ *Share due to the uncertainty effect*	*38%*	*51%*	*50%*	*46%*
$\hookrightarrow$ *Share due to the level effect*	*43%*	*36%*	*39%*	*42%*
$\hookrightarrow$ *Share due to the inequality effect*	*19%*	*13%*	*11%*	*12%*
Average cons.-eq. welfare gain for HS	-0.28%	-0.30%	-0.25%	-0.19%
Average cons.-eq. welfare gain for CD	+1.98%	+1.84%	+1.78%	+1.72%
Average cons.-eq. welfare gain for CG	+1.54%	+1.31%	+1.22%	+1.13%
Education sector				
Share of college enrollees	80.1%	78.7%	78.6%	78.6%
Share of college graduates	33.4%	33.2%	33.1%	33.1%
Skill premium	82.7%	85.8%	86.3%	86.4%
Educational effort	23.0%	23.2%	23.2%	23.2%
Mean ability of enrollees	5.134	5.138	5.139	5.139
Mean parental transfer	$35,999	$35,829	$36,087	$36,032
Average net worth of CG	-$7,234	-$6,933	-$6,128	-$6,138
Average net worth of CD	$2,581	$2,824	$2,958	$2,961
Average net worth of HS	$27,600	$25,646	$25,668	$25,622
Borrowers qualifying for ICLs	41.0%	43.2%	45.6%	47.9%
Mean repayment by CG	$392	$748	$1066	$1355
Mean repayment by CD	$127	$253	$380	$507
Labor income tax rate	35.9%	35.9%	35.7%	35.6%
Production sector				
Aggregate output	0.284	0.283	0.283	0.283
Aggregate capital	0.372	0.370	0.370	0.370
Interest rate r	5.8%	5.8%	5.8%	5.8%
Labor hours of CG	35.7%	35.6%	35.6%	35.5%
Labor hours of CD	32.9%	32.9%	33.0%	33.0%
Labor hours of HS	31.5%	31.5%	31.5%	31.5%

Table 11: Aggregate statistics of economies with ICLs and different repayment limits

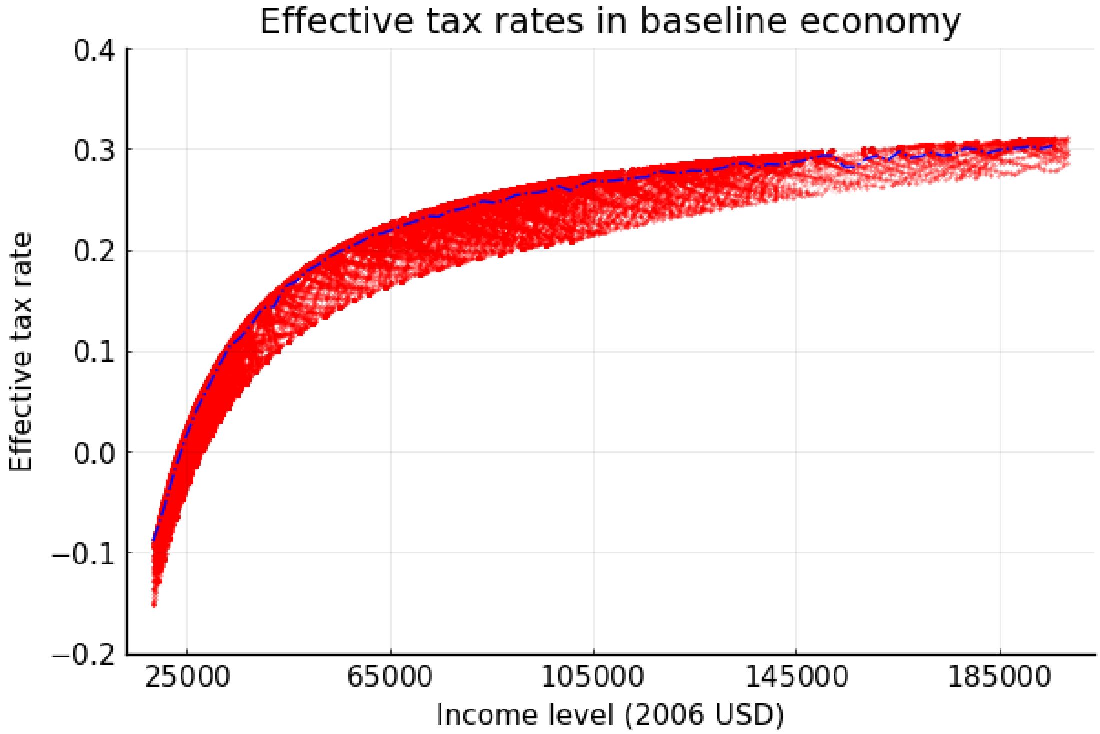

Figure 7: Effective average income tax and distribution

Note: Effective income tax is computed as a 1-(post-government income)/(pre-government income), where pre-government income is a sum of labor and capital interest income; and post-government income is the latter sum net of taxes plus lump-sum transfers and forgiven debt (if any).

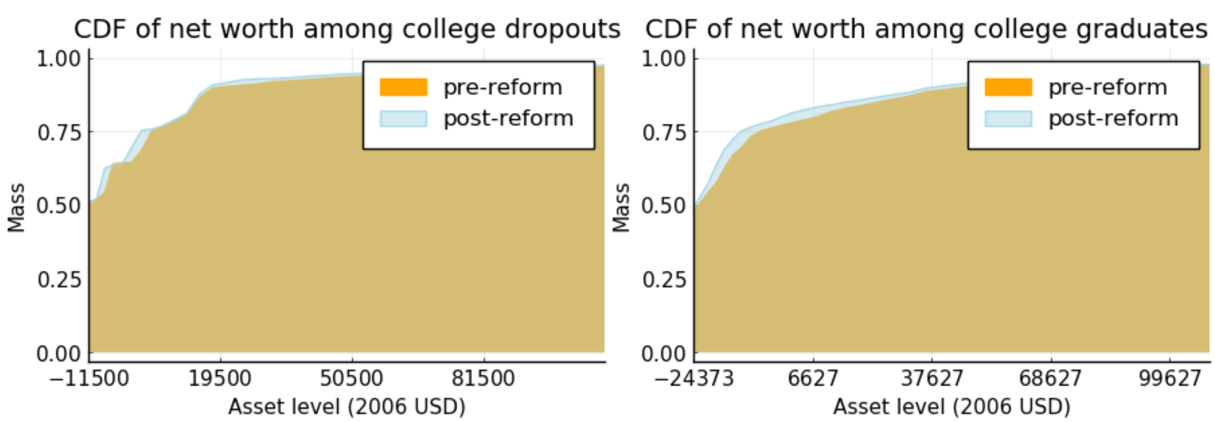

Figure 8: Cumulative distribution of net worth for college dropouts and graduates

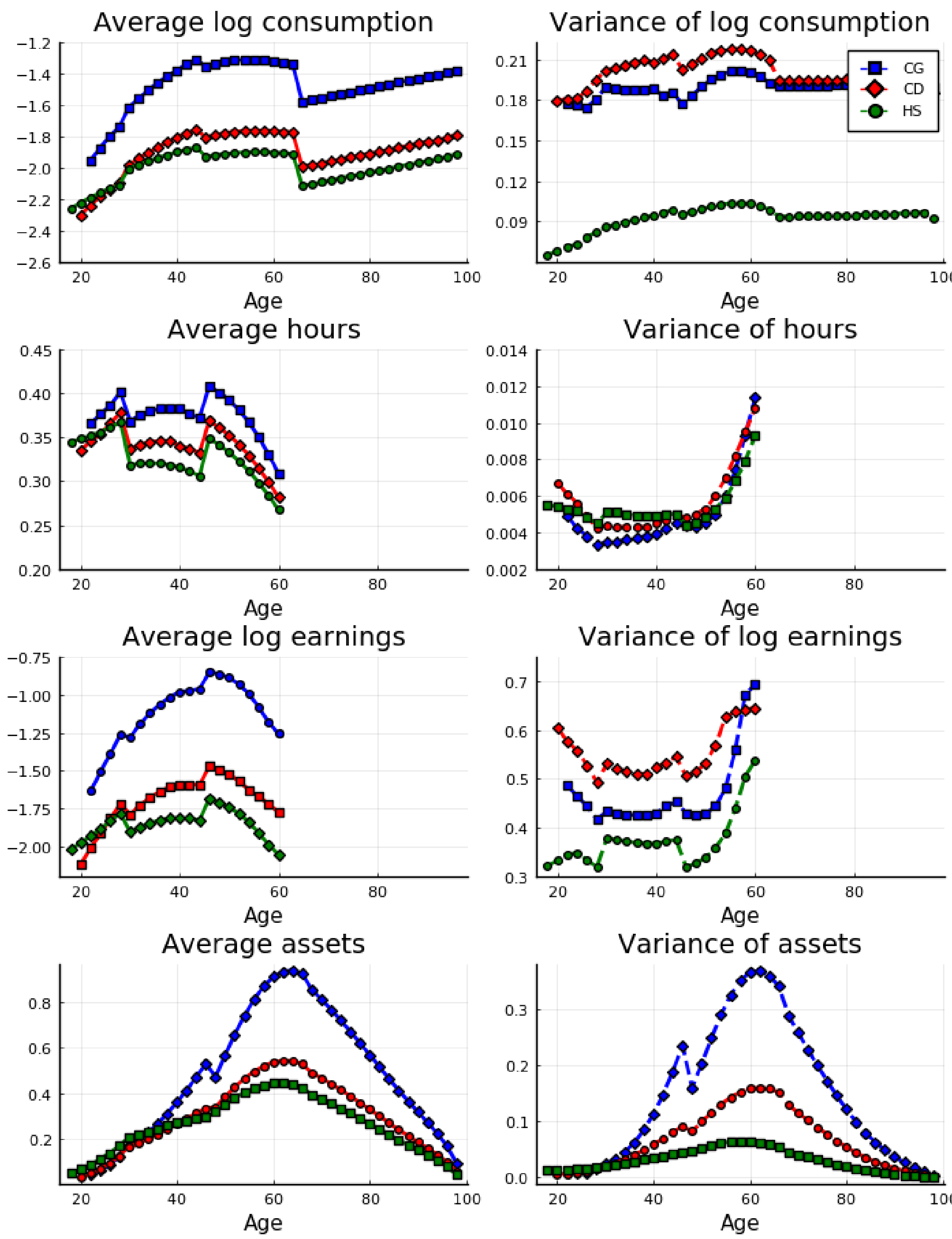

Figure 9: Life-cycle profiles by education

Note: Plots start in periods of finishing education, i.e. for HS from age 18, for CD from age 20, and for CG from age 22.

parameter	interpretation	value	target/source
$p_\theta(\theta)$	θ-dependent slope of graduation prob. f-n	(1.15, 0.865, 1.01, 1.24)	grad. profile, Fig. 2/NLSY97
$\lambda_\theta(\theta)$	θ-dependent psychic cost	(-4.17, -11.7, -18.3, -21.8)	enrol. profile, Fig. 2/NLSY97
λ_χ	college taste-slope	30.2	enrol. profile, Fig. 2/NLSY97
a^S	productivity of skilled labor	0.587	CG-HS skill premium, CPS
ϵ^{CD}	productivity intercept of CD	1.09	CD-HS wage premium, CPS
μ	consumption share of preference	0.406	7.5 hours of work per day
β	time discount rate	0.949	capital/output ratio, F.-V. and K. (2011)
ν	altruism parameter	0.114	transfer/mean income at 48, Daruich (2018)
ψ	lump-sum transfer	0.0325	log pre-tax/post-tax income, HPV (2010)

Table 12: Calibration summary for the economy with $\rho = \infty$

Note: The table presents parameter values in the economy with exogenous skill premium that differ from the ones in Table 3.