College Education and Income Contingent Loans in Equilibrium: Theory and Quantitative Evaluation

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Abstract

We investigate the welfare implications of income-contingent loans (ICLs) used for financing college education in presence of the dropout risk that depends on unobservable effort. Using a simple model, we show that the laissez-faire enrollment is inefficiently low due to missing insurance against dropping out. However, providing this insurance generates a moral hazard cost of lowering effort. We show that ICLs can implement the second best allocation. Then, we construct a heterogeneous agent OLG life-cycle model, calibrate it to the US and show that ICLs significantly increase welfare and that their non-linear structure is essential to delivering high welfare gains.

Keywords: Human Capital, College Education, Endogenous Skill Premium, Income-Contingent Student Loans

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 2019 reaching $1.6 trillion (making it the second largest debt category after mortgages).[1] Importantly, however, these costly investments into higher education are risky as around 50% of college enrollees drop out before earning a bachelor's degree. Furthermore, some of the college dropouts end up locked in low-paying jobs and consequently find it difficult to repay their student debt under standard loan programs characterized by fixed repayment amounts.

It is exactly for these reasons that experts in many countries have argued for provision of income-contingent loan (ICL) programs, under which repayments increase in the current labor income, with borrowers below some poverty threshold facing no repayments.[2] In the US, the first major ICL program ("Income-Based Repayment") was enacted by the College Cost Reduction and Access Act of 2007 and was made available in July 2009.[3] 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 2017, the share of borrowers using ICL programs increased from 9.5% to 27%, with the total balance of loans in these programs going up from 12% to 45% [CBO, 2020].

In this paper, we evaluate the welfare impact of ICL programs in a macroeconomic environment with uninsurable college dropout risk. We begin by constructing a two-period model of risky college education with students deciding about enrolling into college and exerting educational effort. Enrollees are subject to uninsurable college dropout risk that is a function of unobservable effort exerted. Using this framework, we show theoretically that the laissez-faire enrollment is inefficiently low, compared with the relevant second-best allocation providing insurance against the dropout risk, as defined later. However, such interventions need to be carefully balanced as they come with the cost of reducing incentives for exerting educational effort due to moral hazard.

Confirming the rationale of policy proposals mentioned above, we show that an appropriately designed integrated system of ICLs and income tax can decentralize the second best allocation while accounting for the moral hazard generated by unobservable educational ef-

[1] According to the Federal Reserve data (see: https://www.federalreserve.gov/releases/g19/HIST/cc_hist_memo_levels.html).

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

[3] The first ICL program "Income-Contingent Repayment" was introduced in the US in 1994, but was used by few college enrollees.

fort. As such, we highlight that ICLs can be welfare improving but come with an important trade-off of encouraging higher college enrollment at the cost of reducing educational effort.

In order to investigate these issues quantitatively, we extend our simple theoretical model into a rich life-cycle overlapping generations heterogeneous agents economy, with endogenous skill premium[4] and other general equilibrium effects, incomplete markets and intergenerational linkages. Newborns receive endogenous inter-vivo transfers from their parents, decide about pursuing risky college education, borrowing and part-time work. After leaving college, they repay their student debt, accumulate savings and make labor supply decisions in presence of the idiosyncratic labor productivity shocks. As a final component, there is a government administering a progressive tax and subsidy system, grants, loans and pensions.

We carefully calibrate our experimental economy to match the properties of the US tax system, education and labor markets in the year 2006, right before 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 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 documented in the literature enrollment and graduation responses on impact of a $1,000 increase in subsidies.

Our reform experiment introduces ICLs in a way mimicking the current institutional setup in the US, where borrowers repay 10% of their current labor income earned in excess of 150% of the federal poverty threshold, i.e. $\$30,000$ annually. In line with our theoretical results, we find that this reform substantially reduces the loan repayment risk stemming from graduation and idiosyncratic labor productivity shocks, as demonstrated by a 5.4% increase in enrollment. However, by providing this insurance, the reform also reduces the incentives for providing educational effort, as evinced by a 5% drop in the share of time spent studying. In terms of aggregate changes induced by ICLs, we find that the skill premium contracts by 7%. Overall, the policy brings a significant welfare improvement equivalent to a 1.14%

[4] We define the skill premium as the ratio of mean labor income of college graduates to mean labor income of high school graduates.

increase in permanent consumption on average. Importantly, we also find that all education groups benefit from the reform - either due to reduction in the skill premium (which benefits high school graduates and college dropouts) or reduction in student loan repayment risk (which benefits college dropouts and graduates). Finally, we move on to a comparative statics exercise, where we vary the degree of insurance 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 insurance benefits of ICLs to individuals who need it more on average.

Literature review. Relating to the theoretical part of our paper, [Gary-Bobo and Trannoy, 2015] and [Findeisen and Sachs, 2016] both study dynamic environments of one-shot risky college education where students posses private information about their ability and effort exerted. They show that a Pareto optimal allocation can be implemented using an integrated tax and student loan system with income-contingent repayment rates. Similarly, [Stantcheva, 2017] studies optimal policies with human capital accumulation over life-cycle and also finds that the second best allocation can be implemented with the combination of income-tax enhanced by ICLs. To the best of our knowledge, our paper is the first in the literature to theoretically analyze the second best allocation in a model with joint determination of equilibrium enrollment and educational effort in presence of uninsurable graduation shocks. Thus, we are also the first to show how the ICL-based decentralization is associated with an important trade-off due to affecting both margins of enrollment and effort.

Furthermore, the second best implementation with student loans is naturally related to the literature studying borrowing constraints in the context of education. To this end, [Lochner and Monge-Naranjo, 2012] review this literature and conclude that in recent years credit constraints have become an important determinant of educational outcomes among the youth. On the other hand, [Keane and Wolpin, 2001] and [Johnson, 2013] estimate structural models of higher education and find that relaxing borrowing constraints has a only modest impact on educational attainment. However, even if borrowing constraints were not binding, people may still choose not to borrow more due to the significant repayment risk. To this end, we show in this paper that the insurance-component embedded in ICLs addresses this issue and so can lead to a significant increase in borrowing for education.

Regarding quantitative evaluation of ICLs in the US, both [Findeisen and Sachs, 2016] and [Stantcheva, 2017] complement their theoretical analyses with numerical exercises evaluating the welfare gains associated with pursuing the policies prescribed by the second best allocation. Using a quantitative model with job search, [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. They also show that ICLs can alleviate this trade-off. Furthermore, [Ionescu, 2009] evaluates the US student loan system through the lenses 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 and exogenously given wage rates in order to study the students' welfare under ICLs and student debt default allowing for discharging or reorganizing debt regimes. Using a two-period model of education with exogenous college costs, graduation probabilities and 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] and [Matsuda, 2020] study dynamic OLG economies with human capital accumulation and financial constraints. They use their models to 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 general equilibrium effects working through an endogenous skill premium and the equity-efficiency trade-off implied by endogenous educational effort subject to moral hazard.

Along their in-depth review of the literature, [Lochner and Monge-Naranjo, 2016] discuss optimal student loan policy recommendations. Using a simple theoretical model, 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 complements their work by (i) pointing out importance of the endogeneity of the skill premium in relation to student loan policies adopted, and (ii) analyzing the optimal design of ICLs in a rich macroeconomic environment.

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, 2016] and [Krueger and Ludwig, 2013]. Most of these papers allow for general equilibrium effects of government policies on relative factor prices. In this paper, we take a closer look at the general equilibrium effect working through a skill premium and the associated insurance role of student loans.

Structure. This paper is organized as follows. In the next section, we outline the two-period model and characterize the laissez faire equilibrium and second best allocations.

Section 3 develops the quantitative model, with description of its calibration strategy in Section 4. The results of the quantitative analysis are presented in Section 5. We conclude the paper in Section 6.

2 Theoretical Model

In this section, we first introduce our two-period human capital model. After this, we characterize the laissez-faire equilibrium and the allocation implementing second best using ICLs, and derive our key theoretical predictions regarding college enrollment and educational effort.

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:

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

subject to budget constraint of:

$$c_e + (1+r)\,\varphi \cdot \mathbf{1}_{e\in\{CD,CG\}} \leq w_e \ \forall e \in \{HS, CD, CG\} \tag{2}$$

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.[5]

Laissez Faire Equilibrium

The laissez faire (LF) competitive equilibrium is a list of optimal enrollment and educational effort decisions maximizing (1) subject to (2). Since the problem is concave, the ensuing equilibrium is unique.

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

$$\chi \geq \bar{\chi} \equiv u\left(c_{HS}^{LF}\right) - \left[p(h_e^{LF})u\left(c_{CG}^{LF}\right) + (1-p(h_e^{LF}))u\left(c_{CD}^{LF}\right) - v(h_e^{LF})\right] \tag{3}$$

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. $\Phi = \frac{\bar{\chi}-a}{b-a} \in (0,1)$.

[5] One example of such a state-contingent claim could be a long-term contract between a student and a firm providing insurance against college dropout risk. With this in mind, the assumed market incompleteness can be micro-founded by limited commitment on agents' side. In particular, in a world with such long-term contracts available, any successful student would have incentives to default on their contract and go to work in another firm offering a market wage rate. This mechanism would lead to collapse of such markets in equilibrium.

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

$$v'\left(h_e^{LF}\right) = p'\left(h_e^{LF}\right)\left(u\left(c_{CG}^{LF}\right) - u\left(c_{CD}^{LF}\right)\right) \tag{4}$$

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.

Second Best Allocation and ICLs

We move on to characterizing the second best allocation where the planner can redistribute resources across agents, but has to account for the incentive compatibility constraints on enrollment and educational effort. Then, we discuss its decentralization with an integrated system of ICLs and income taxes, and ultimately we investigate the impact of ICLs on enrollment and graduation.

The planning problem reads:

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

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

subject to:

$$\begin{aligned} (\mu)\ \ \Phi \cdot c_{HS}^{SB} + (1-\Phi) \cdot \left(p\left(h_e^{SB}\right) c_{CG}^{SB} + \left(1 - p\left(h_e^{SB}\right)\right) c_{CD}^{SB}\right) \leq \\ \Phi \cdot w_{HS} + (1-\Phi) \cdot \left(p\left(h_e^{SB}\right) w_{CG} + \left(1 - p\left(h_e^{SB}\right)\right) w_{CD} - (1+r)\varphi\right) \end{aligned} \tag{5}$$

$$(\psi_e)\ \ h_e^{SB} = \text{argmax}_{\tilde{h}_e} \{p\left(\tilde{h}_e\right) u\left(c_{CG}^{SB}\right) + \left(1 - p\left(\tilde{h}_e\right)\right) u\left(c_{CD}^{SB}\right) - v\left(\tilde{h}_e\right)\} \tag{6}$$

$$(\psi_\Phi)\ \ \bar{\chi} = u\left(c_{HS}^{SB}\right) - \left[p(h_e) u\left(c_{CG}^{SB}\right) + (1 - p(h_e)) u\left(c_{CD}^{SB}\right) - v(h_e^{SB})\right] \tag{7}$$

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

It is well understood that the second 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:[6]

$$v'\left(h_e^{SB}\right) = p'\left(h_e^{SB}\right)\left(u\left(c_{CG}^{SB}\right) - u\left(c_{CD}^{SB}\right)\right) \tag{8}$$

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

The condition (8) 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 (8) since:

$$-v''(h_e) + p''(h_e)\left(u\left(c_{CG}^{SB}\right) - u\left(c_{CD}^{SB}\right)\right) < 0 \ \forall h_e \tag{9}$$

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.[7] Thus, we now explore a way of implementing this allocation as a decentralized competitive equilibrium with an integrated system of income tax τ_{HS} and income-contingent debt repayment rates $\varphi_{CD}, \varphi_{CG}$. While the objective function of agents is the same as (1) in the laissez faire equilibrium, the budget constraints take the following form:

$$c_{HS}^{dec} \leq (1 - \tau_{HS}) w_{HS} \tag{10}$$

$$c_e^{dec} + (1 + r)\varphi_e \leq w_e \text{ if } e \in \{CD, CG\} \tag{11}$$

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 (3) and (4).

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

Proposition 1 *The competitive equilibrium with the following joint system of (i) income tax for high school graduates, and (ii) income-contingent student loan repayment rates attains the second best allocation:*

$$\tau_{HS} = 1 - \frac{c_{HS}^{SB}}{w_{HS}} \tag{12}$$

$$\varphi_{CD} = \frac{w_{CD} - c_{CD}^{SB}}{1 + r} \tag{13}$$

$$\varphi_{CG} = \frac{w_{CG} - c_{CG}^{SB}}{1 + r} \tag{14}$$

where c_{HS}^{SB}, c_{CD}^{SB}, c_{CG}^{SB} are the second best consumption allocations of CG, CD and HS.

Furthermore, this allocation satisfies the following government budget balance condition:

[7] Lemma 1 in Appendix A provides the first order conditions characterizing the second best allocation. Furthermore, Lemma 2 (also in Appendix A) shows that the second best allocation is characterized by partial insurance against the dropout risk.

$$\Phi \tau_{HS} w_{HS} = (1-\Phi)\left[p\left(h_e^{dec}\right)\varphi_{CG} + \left(1-p\left(h_e^{dec}\right)\right)\varphi_{CD} - \varphi\right] \tag{15}$$

Proof See Appendix A.

Thus, the social planner may choose income tax and income-contingent repayment rates such that the second best levels of enrollment, effort and consumption are attained.[8]

Since we want to understand the pure effect of ICLs on enrollment and graduation, we need to control for the effects of τ_{HS} on enrollment, i.e. redistribution between high school graduates and enrollees. To this end, we consider the case where we limit $\tau_{HS} = 0$ as follows:

Proposition 2 *There exist policy instruments $\tau_{HS} = 0$ and φ_{CD} and φ_{CG} implementing as a competitive equilibrium the second best allocation SB' subject to additional constraint $c_{HS}^{SB'} = w_{HS}^{SB'}$. 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 See Appendix A.

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.

Importantly, the characteristics of ICLs in our implementation are in line with suggestions of [Lochner and Monge-Naranjo, 2016] who argue that the optimal design of the student loan system has to be such that (i) loans are fully repaid in aggregate; (ii) it provides insurance against dropping out of college; and (iii) it provides right incentives for studying (given the distortion coming from the insurance).

[8] Notice that ICLs improve the welfare because of the (assumed) government's power to "complete" the markets by offering different repayment rates conditional on education outcomes. In practice, enforcement of these contracts is facilitated by the ability of governments to garnish wages, impose additional taxes or withhold tax returns.

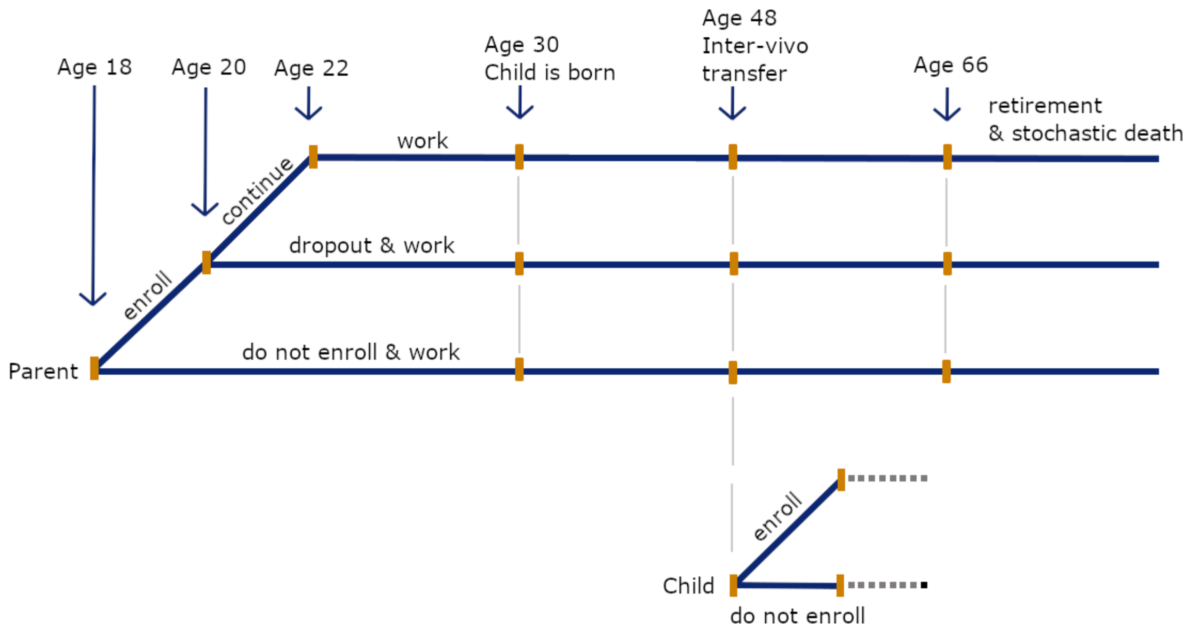

Figure 1: Timeline of events in the quantitative economy

Finally, we acknowledge that our results are derived in a very stylized theoretical environment that hinges on many implicit assumptions. In order to examine the welfare gains of ICLs in the US and investigate their optimal design, we construct in the next section a quantitative framework featuring rich heterogeneity between agents capturing differences in enrollment and educational effort patterns and general inequality, life-cycle considerations capturing consumption smoothing role of ICLs, and endogeneity of the college wage premium allowing us to account for relevant general equilibrium effects.

3 Quantitative Model

This section describes our experimental economy. It 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 uninsurable dropout risk. As adults, workers have their offspring and decide about the size of inter-vivo transfers. Figure 1 summarizes the life-cycle of agents living in our economy.

Moreover, there is a government administering programs of loans and subsidies for college education, progressive redistribution system and collecting tax for these purposes. All these 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 4 below (with Table 3 summarizing all the parameter values assumed). Furthermore, 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.

3.1 Demography

Time is discrete. The economy is populated by J concurrently living generations of continuum of agents of age $j \in \{1, 2, \ldots, J\}$. Workers in the economy are characterized by one of three education types: 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 time, 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 in that students may drop out after the first period of education.

From age 20 onward ($j \geq 2$; if agent is a dropout) and 22 onward ($j \geq 3$; if agent is a graduate), agents face usual life cycle decision problems. In each period, agents have a unit of time available. At the biological age of 30, i.e. at age $j_f = 7$ $(= (30 - 18)/2 + 1)$, they give birth to children that become 2 years old by the end of the period. At age $j_b = 15$ (biological age 46), agents decide about the size of wealth transfers to their children who then become independent.[9] 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 periods between j_r and $J - 1$ from the US Life Tables 2000.

3.2 Preferences

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

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

[9] We do not allow for parental transfers at any other age. Relaxing this assumption would lead to severe computational complications as then state variables of parents would have to include state variables of their children.

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. 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 4), as is standard in the literature. 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 heterogeneous psychic cost of attending college with $\mathbf{1}_c$ being an indicator function equal to 1 if the newborn enrolls into college. This cost depends on in-born ability θ. The third term stands for (unobservable to the econometrician) college taste χ accruing in the first period of college, where $\mathbf{1}_{c,j=1}$ is an indicator function equal to 1 if the newborn enrolls in the first period of college. Including college taste 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. Section 3.5 below explains ability and college taste in more detail.

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 detail below.

3.3 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 relationship between the relative supply of skilled labor and the skill premium. We set ρ so that this elasticity equals 1.64, as in [Goldin and Katz, 2009].

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:

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

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

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.[10] 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, we denote by $\varepsilon_j^e(\theta, \eta)$ the effective labor per hour. It depends on the education level e, age j, ability θ and idiosyncratic productivity η. The latter follows a mean-reverting and education-specific Markov chain $\pi^e(\cdot|\eta)$. For future reference, we denote by Π^e the invariant distribution of shocks η.

3.4 Financial Markets

The structure of financial markets is incomplete due to the lack of state-contingent claims providing insurance against 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 fees. As most of student loans in the US are federal, we assume no access to private borrowing.

We design the benchmark economy such that it matches the 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

[10]They 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.

mimics the US student loan system after the introduction of ICLs.

Fixed Repayments

The properties of student loans in our benchmark economy are based on the Stafford loan program (from the Federal Family Education 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.[11] In our implementation, we assume that fresh college enrollees borrow half of the full amount of student loan $0.5\underline{A}^c = \$11,500$. Then, conditional on passing first 2 years of college, enrollees borrow additional $0.5\underline{A}^c$ in period 2, exhausting the overall borrowing limit of the Stafford loan program.

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. For the latter, we assume that lenders incur the cost of monitoring borrowers equal to $\iota > 0$ per unit of capital. Thus, the no arbitrage condition for lenders implies that the interest rate on education loans equals $r^- = r + \iota$, with $\iota = 2.3\%$ annually.[12]

This discussion implies that the student loan repayments amount to:

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

where j^* is the period 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 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.[13]

Furthermore, it is obviously not the case in reality that every enrollee borrows up to the maximum of the student loan limit. 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

[11] Stafford loans can be either subsidized or unsubsidized (with government paying for the loan interest while in college, or not). We focus our quantitative analysis on unsubsidized loans.

[12] We choose the value of interest rate premium following U.S. Department of Education: https://www2.ed.gov/programs/ffel/index.html

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

aside in a risk-less saving account accruing interest rate r in all periods of their life (including both periods of education). In particular, if the interest rates between savings and borrowing were equivalent, this approach would be without loss of generality, as agents would be able to offset any undesirable borrowing with 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, while the amount of borrowing is the same as under Fixed Repayments, the ICL reform lowers the workers' repayment risk due to the uninsured college dropout and idiosyncratic productivity shocks. It does so by introducing a non-linear repayment schedule where workers with a labor income falling below the poverty threshold $\bar{y}$ do not face any repayments in a given period, and the ones with income above it repay ω-portion above $\bar{y}$.

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

$$\bar{\ell}_{j^*}(e,y)^{ICL} = \begin{cases} \min\{\omega \cdot \max\{0, y - \bar{y}\}, \bar{\ell}_{j*}(e)^F\} \text{ if } j^* \leq \bar{T} \\ 0 \text{ if else} \end{cases} \tag{16}$$

where $\bar{T} = 10$ stands for the number of repayment periods (the same as under fixed repayments), $\bar{y}$ is 150% of the federal poverty threshold equal to \$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, the ICL's repayment length parameter $\bar{T}$ constitutes at the same time a parameter governing the period after which any outstanding debt is forgiven. This important feature provides insurance to the very unlucky agents experiencing many low productivity shocks who would not be able 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 $\bar{\ell}_{j*}(e)^F$, in line with institutional design in the US (see [CBO, 2020]). This means that ICLs are subsidized by government and so are strictly preferable to the loans with fixed repayment schedules.

3.5 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.[14]

[14] 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."

Enrollment Stage

In period 0, 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:

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

where a is the agent's current saving position, θ - her in-born 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^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:

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

subject to:

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

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

$$a' \geq 0, \;\; c \geq 0, \;\; 0 \leq h_l + h_e \leq 1, \;\; h_l \in [0,1], \;\; h_e \in [0,1]$$

Attending the first period of college is associated with borrowing of $0.5\underline{A}^c$ for the first two years of their college education. Furthermore, agents attending college have to bear the psychic cost $\lambda_\theta(\theta)$ and invest fraction h_e of time available in order to increase their probability of graduation. Apart from this, students decide about their savings $a' \geq 0$ (determining their net worth in next period) and labor hours h_l (supplied as high school graduates). They also have to pay the total tax $T(c,a,y)$, which depends on their consumption, current net worth and earnings.

Notice that the optimal college enrollment decision depends on four state variables: (i) initial net worth a endogenously determined as a transfer from their parents; (ii) the in-born ability θ which is stochastically inherited from parents; (iii) the idiosyncratic productivity η drawn from Π^{HS}; and (iv) college taste shock χ. 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. Finally, advancing into the second half of college education is stochastic given effort taken, capturing residual uncertainty such as learning about enjoyability in college, health, financial shocks and so on.

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[15] $s = \$1,183$; and (ii) annual tuition fee (net of institutional grants) is[16] $\varphi = \$11,018$.

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:

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

$$a' \geq 0, \;\; c \geq 0, \;\; 0 \leq h_l + \bar{h}_e \leq 1, \;\; h_l \in [0,1], \;\; \bar{h}_e = 0.25$$

[15] 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.

[16] 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.

Notice that we assume that once students enter the second period of college, they graduate with certainty. However, completing the college requires additional borrowing of $0.5\underline{A}^c$ and takes a quarter of their time endowment, i.e. we set $\bar{h}_e = 0.25$. Furthermore, college students in period 2 can provide part-time labor with the productivity level of college dropouts.

Working Stage

The Bellman equation for working stage[17] of individuals looks as follows:[18]

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

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 repayment depending on the institutional setup (fixed or ICL). Notice that 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.

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 $\pi_\theta(\theta,\theta')$. 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:

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

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

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

[17] 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.

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

Importantly, this formulation implies that 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).

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:

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

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

where $P(e,\theta)$ denotes retirement benefits modelled as in the United States 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 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}.

3.6 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 $T(c,a,y) = \tau_c c + \tau_k r a \mathbf{1}_{a\geq 0} + \tau_l y - \psi$, where ψ is the lump-sum transfer (given to each individual) introducing progressivity into the labor income tax schedule.[19] 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.[20] 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 United States in 2006 amounted to 17.8% of GDP (according to data from the U.S. Bureau of Economic

[19]Notice that the proportional capital income tax rate τ_k is levied only on positive net worth a.

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

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 total government spending. We use the labor income tax rate τ_l to balance the budget in each state.

3.7 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 in each period and prices clear all the markets.

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

4 Calibration

This section describes how we parametrize the model. 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 targeting year 2006.

4.1 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:

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

We normalize $\epsilon^{HS} = \epsilon^{CG} = 1$ and calibrate ϵ^{CD} to match the wage premium of college dropouts, as explained later.

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). We use

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

Table 1: Estimated ability slope ϵ_θ^e of labor productivity

Source: NLSY79. See Appendix E for details.

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.

In order to identify the effect of ability on labor productivity, we use the Armed Forces Qualification Test (AFQT) score in the NLSY79. 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.

In order to allow for persistence of idiosyncratic shocks η, we assume that they are drawn from an education-specific Markov chain $\pi^e(\eta'|\eta)$ with two education-specific states η_H^e and η_L^e. We choose the chain's parameters such that it has the same persistence and conditional variance as the following AR(1) process:

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

We estimate this process using a minimum distance estimator with a fixed effect and a measurement error. We target 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 terms of data, we use the PSID since ability is captured by the fixed effect (and so we do not need the AFQT-ability variable from NLSY79). In Appendix E, we discuss sample selection and details of the estimation procedures. Table 2 presents results of the estimation.

Finally, we focus our analysis on young workers (i.e. people who are repaying student debt) for whom unemployment constitutes potentially an important risk. In the US, the mean unemployment duration is rather short[21] (equal to approximately 16.5 weeks in 2006), with the unemployed ones usually qualifying for unemployment benefits.[22] Furthermore,

[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.

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' available 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 to some extent account for unemployment as it allows unproductive agents to endogenously reduce their labor supply.[23]

4.2 Intergenerational Ability Transmission

For modeling ability and its intergenerational transmission, we first assume that ability θ takes one of the values on four grid points. These grid points are equal to the median of ability at each quartile of the ability distribution in NLSY79 (as measured by AFQT and PIAT test scores).[24]

Second, the Markov chain of intergenerational transmission of ability $\pi_\theta(\theta, \theta')$ is estimated using NLSY79 and "NLSY79 Child & Young Adult." 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 (see [Cunha and Heckman, 2007], [Cunha, 2013] and [Daruich, 2018]). See Appendix F for discussion of the sample selection, details of the estimation procedure and Table 7 for the estimated Markov chain.

[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]In particular, the grid is made of points equal to 4.9, 5.1, 5.2 and 5.3.

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
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	(1.17, 0.855, 0.927, 1.24)	grad. profile, Fig. 2/NLSY97
$\lambda_\theta(\theta)$	θ-dependent psychic cost	(-5.72, -14.6, -21.5, -24.4)	enrol. profile, Fig. 2/NLSY97
λ_χ	college taste-slope	33.0	enrol. profile, Fig. 2/NLSY97
a^S	productivity of skilled labor	0.499	CG-HS skill premium, CPS
ϵ^{CD}	productivity intercept of CD	1.09	CD-HS skill premium, CPS
μ	consumption share of preference	0.404	7.5 hours of work per day
β	time discount rate	0.953	capital/output ratio, F.-V. and K. (2011)
ν	altruism parameter	0.116	transfer/mean income at 48, Daruich (2018)
ψ	lump-sum transfer	0.0341	log pre-tax/post-tax income, HPV (2010)

Table 3: Calibration summary

Moment	Model	Data
Enrollment rate of ability quartile	(figure)	(figure)
Graduation rate of ability quartile	(figure)	(figure)
Enrollment rate of family income quartile	(figure)	(figure)
Skill premium for CG	89.7%	90.2%
Skill premium for CD	20.0%	19.9%
Hours of work	32.9%	33.3%
Aggregate capital / output	1.34	1.33
Inter-vivo transfer / mean income at 48	73.4%	72.1%
Var log post-tax / var log pre-tax income	0.60	0.61

Table 4: Moments matched and model fit

4.3 Remaining Parameters

We finalize the model's calibration 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).

Notice that 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. The data on enrollment and graduation rates comes from NLSY97. Since majority 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.[25]

Then, we estimate the wage premiums 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 lump-sum transfer ψ.[26]

[25] This is in line with the above mentioned evidence in [Torpey and Watson, 2014]. See also work by [Hendricks and Leukhina, 2017], [Hendricks and Leukhina, 2018] and [Athreya and Eberly, 2020] following a similar approach.

[26] 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].

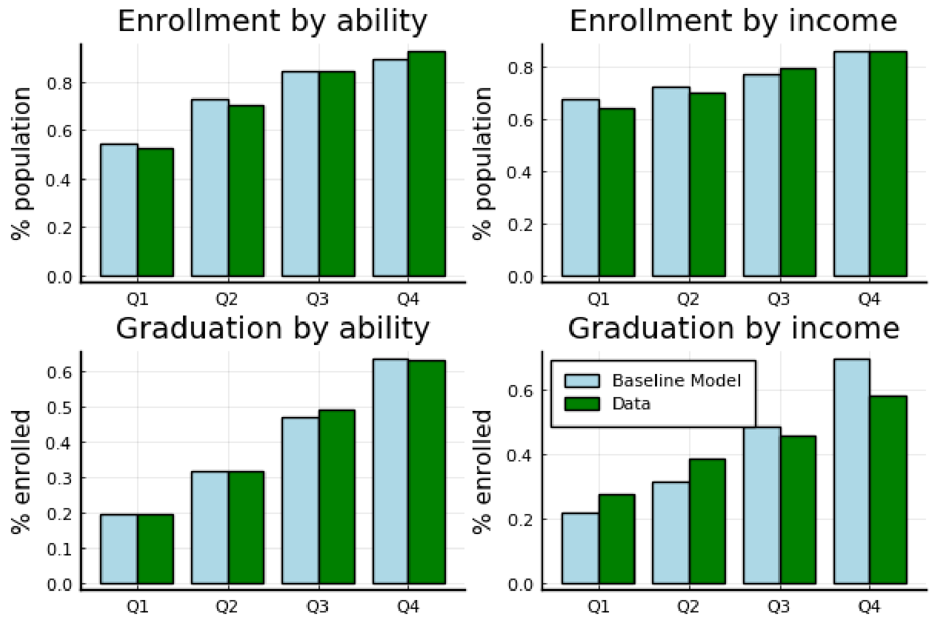

Figure 2: Enrollment and graduation rates by ability and income quartiles

Data Source: NLSY97. We use the sample of only 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.

4.4 Calibration Validation

Table 4 presents the empirical fit of our estimation strategy. Overall, the experimental 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, 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 empirical evidence on the effective tax rates in the US in [Heathcote et al., 2017] (see Figure 6 in Appendix G).[27]

[27]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 using function $T(y) = y - \lambda y^{(1-\tau)}$. Their pre-government (taxable) income includes labor and self-employment income, private transfers (alimony, child support, remittances, private pension income, annuities etc.), plus income from interest, dividends and rents, minus expenses that are deductible in the US (medical expenses, mortgage interest, state taxes paid and charitable contributions). Their post-government income is made of the pre-government income minus taxes (federal and state income taxes and the FICA tax), plus public cash transfers (AFDC/TANF, SSI,

Third, Figure 8 in Appendix G presents the implied life-cycle profiles of consumption, earnings and asset margins. 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 in [Guvenen, 2009].

Finally, we simulate the partial equilibrium response of enrollment to a $1,000 increase in subsidies for all years in college and family income evenly[28] and find that (i) the aggregate enrollment rate of the affected generation increases by 1.80 p.p., and (ii) the share of college graduates increases by 2.58 p.p. The first number is close to the empirical evidence in [Dynarski, 2002] and [Cameron and Heckman, 2001] who argue that the enrollment rate of groups that benefit from such a subsidy increases by between 3 and 6 p.p. Similarly, the increase in graduation rate is just in line with the evidence in [Scott-Clayton, 2011], who finds that a $1,000 increase in subsidies results in a 2.59p.p. increase in graduation rate.[29] Thus, the behavior of students implied by our model is within the estimates of the literature.

5 Results

In this section, we discuss main quantitative results of the paper. We begin by evaluating the equilibrium impact of the 2009 reform introducing ICLs in the US. By comparing the ex-ante welfare of 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 in the US is significantly enhanced by presence of the poverty threshold exempting low earners from loan repayments.

Evaluating US ICL System

Table 5 presents the impact of the reform introducing ICLs on the US economy. First of all, we observe that the introduction of ICLs increases college enrollment by 5.4 p.p. (or 7.2%) as the repayment risk associated with using student loans is lowered. This triggers increases in borrowing among enrollees, as evinced by significant declines in average net worth of

unemployment benefits, workers' compensation and veterans' pensions).

[28] All prices and the distribution at age 1 are fixed at the current level, and these additional subsidies are given to only one generation.

[29] The positive effect of subsidies on graduation rate is also broadly in line with results in [Dynarski, 2008], [Castleman and Long, 2016], [Scott-Clayton and Zafar, 2019], [Denning et al., 2017], and [Bettinger et al., 2019].

Statistic	**Fixed**	**ICL**
Welfare		
Average cons.-eq. welfare gain		+1.14%
Average cons.-eq. welfare gain for HS		+0.12%
Average cons.-eq. welfare gain for CD		+1.95%
Average cons.-eq. welfare gain for CG		+1.12%
Education sector		
Share of college enrollees	74.6%	80.0%
Share of college graduates	31.4%	32.4%
Skill premium	89.7%	84.1%
Share of time studying	23.0%	21.9%
Mean ability of enrollees	5.144	5.134
Mean parental transfer	$37,999	$37,271
Average net worth of CG	-$4,707	-$7,467
Average net worth of CD	$6,501	$4,548
Average net worth of HS	$24,036	$28,693
Borrowers qualifying for ICLs	N/A	47.9%
Mean repayment by CG	$2,097	$1,321
Mean repayment by CD	$992	$497
Labor income tax rate	35.7%	36.0%
Production sector		
Aggregate output	0.284	0.285
Aggregate capital	0.380	0.381
Interest rate r	5.5%	5.5%
Labor hours of CG	36.3%	35.3%
Labor hours of CD	32.9%	32.6%
Labor hours of HS	31.3%	31.1%

Table 5: Aggregate statistics of economies without and with ICLs

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 (USD11,500 for CDs and USD 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).

dropouts and graduates (see also distributions of borrowing pre- and post-reform in Figure 7 in Appendix G). Although this institutional change attracts more enrollees, the mean ability of students declines by 5% of the standard deviation. Furthermore, ICLs reduce the mean level of educational effort by 1.1 p.p. (or 5%) as the insurance provided through ICLs erodes the incentives for a successful completion of college. Moreover, although mean educational effort declines, the share of college graduates increases by 1 p.p. as the positive response of the enrollment margin dominates the negative change in effort, showing that the insurance gains provided by ICLs exceed the social costs generated by moral hazard. Finally, 47.9% of enrollees in our model benefits from repayment flexibility provided by ICLs. While [CBO, 2020] shows that the take-up of ICLs in the data is around 50% lower, [Cox et al., 2020] argue that this is due to behavioral biases and informational frictions.

Importantly, ICLs in our quantitative framework affect incentives for educational effort through two additional channels, as compared with the simple model in Section 2. First, our quantitative model features endogenous skill premium, which is reduced by 5.6 p.p. as ICLs stimulate higher enrollment and graduation. This effect reinforces the direct effect of reducing effort incentives through insurance provision. Second, based on the actual institutional design in the US, we assume that the repayment rate ω for earnings above $\bar{y}$ is the same for both the dropouts and graduates, while this is generally not the case in the theoretical model. By equalizing repayments between the two groups (conditional on not exceeding the repayment limit from the fixed repayment schedule), this assumption effectively favors graduation relative to dropping out, and as such provides incentives for increasing educational effort. Nonetheless, we see that this channel turns out to be of a second order importance.

Further results in Table 5 show that the reform comes with a significant increase in the utilitarian welfare of newborns[30] equivalent to a 1.14% permanent increase in their consumption. Decomposing this effect by education levels, high school graduates gain 0.12%, with college dropouts and graduates gaining 1.95% and 1.12% (respectively).[31] The gains to high school graduates come from compression in the skill premium implying higher wage rates in the unskilled sector. College dropouts have the highest gains since they benefit from both (i) increases in the wage rate for unskilled workers, and (ii) a 50% reduction in repayments on average. Analogically, college graduates benefit less than college dropouts, but more than high school graduates, because (i) the nominal wage rate for skilled labor declines; and (ii) they benefit from a 37% reduction in repayments on average. From the aggregate economy perspective, we observe a 0.4% increase in output, a 2% decline in mean parental transfers,

[30]Equal to the sum of life-time utilities of newborns with equal weights.

[31]These numbers do not add up precisely to the aggregate effect of 1.14% because of the way we construct them, as explained in the footnote below Table 5.

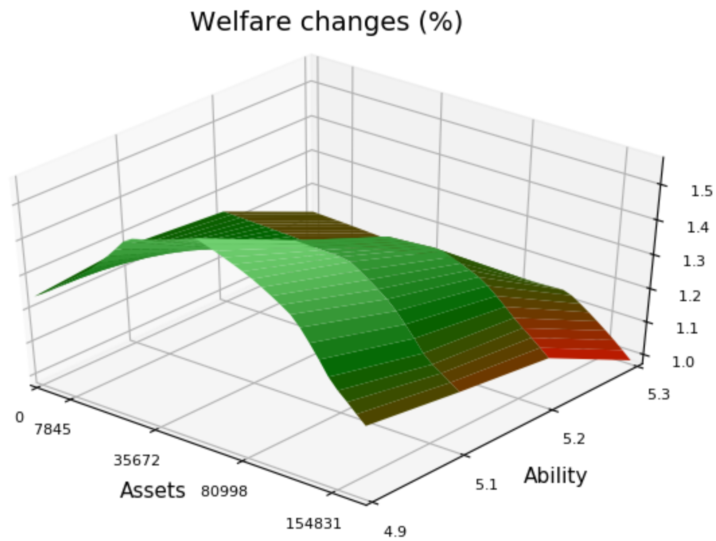

Figure 3: Welfare impact of ICL reform

Note: Ability stands for θ in the labor productivity term $\exp(\epsilon_\theta \cdot \theta)$, see Section 4.1. Assets are expressed in thousands of 2006 US Dollars.

mild declines in labor hours of 0.2-1.0 p.p. across all the education groups and a 0.3 p.p. increase in the labor income tax rate needed to balance the government budget due to the subsidized nature of ICLs.

In order to understand better heterogeneous effects of the reform, we show in Figure 3 the distribution of welfare gains for newborns across their wealth and ability states. While the reform benefits everyone, we find that those with lowest ability and low-medium wealth benefit the most from the reform due to increases in the option value of enrolling into college. Individuals with high initial wealth and ability gain significantly less as they were much more likely to graduate from college and have no difficulties with student loan repayments even before the introduction of ICLs. Figure 4 confirms this intuition: while enrollment strictly increase for all groups, the largest increases are concentrated among the newborns with below median ability and income. Essentially, these differential dynamics reflect the fact that ICLs have the highest insurance value for disadvantaged groups. Furthermore, graduation rates of all groups decline only marginally, confirming again that the social costs generated by moral hazard are small compared to insurance gains provided by ICLs.

As already mentioned, endogeneity of the skill premium constitutes a source of additional insurance to college enrollees and redistribution towards the high school graduates. Thus, we highlight its role by solving for the stationary equilibrium in the recalibrated model with perfect substitution between skill types (i.e. $\rho = \infty$). Table 8 in Appendix G presents results of this exercise. Due to the fact that in this case ICLs do not trigger additional insurance

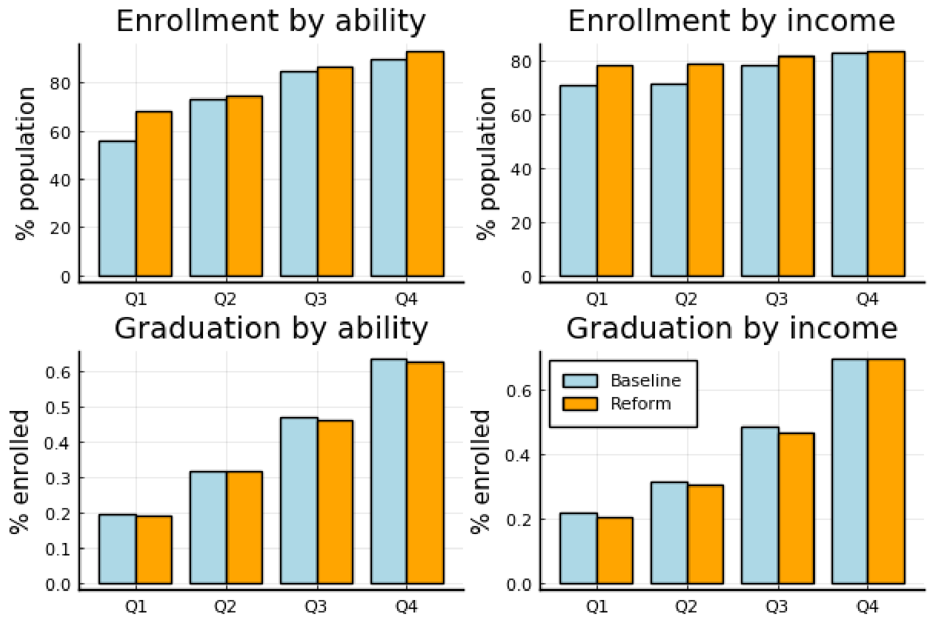

Figure 4: Enrollment and graduation rates impact of ICL reform

and redistribution through adjustments in the skill premium, we observe that the effects on enrollment and mean educational effort become weaker. Interestingly, because the social costs due to moral hazard are milder, the overall welfare gain of ICLs is slightly higher than with the endogenous skill premium (1.18% vs 1.14% before). Nonetheless, in this case the high school graduates are worse off by -0.12% of consumption in every period due to the fact that their wages do not increase anymore on impact of ICLs.

Finally, due to computational complexity of our experimental 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 5.6 p.p. reduction in skill premium. As [Krueger and Ludwig, 2013] point out, adjustments in the aggregate skill premium take long time because the first affected cohorts constitute a small fraction of the overall labor force. Thus, it would normally take many generations for the skill premium to converge to its new steady state. As such, the welfare gains of college graduates in first cohorts would increase as their wage rates would not decline much on impact, and the welfare gains of dropouts and high school graduates would decline for the exactly opposite reason.

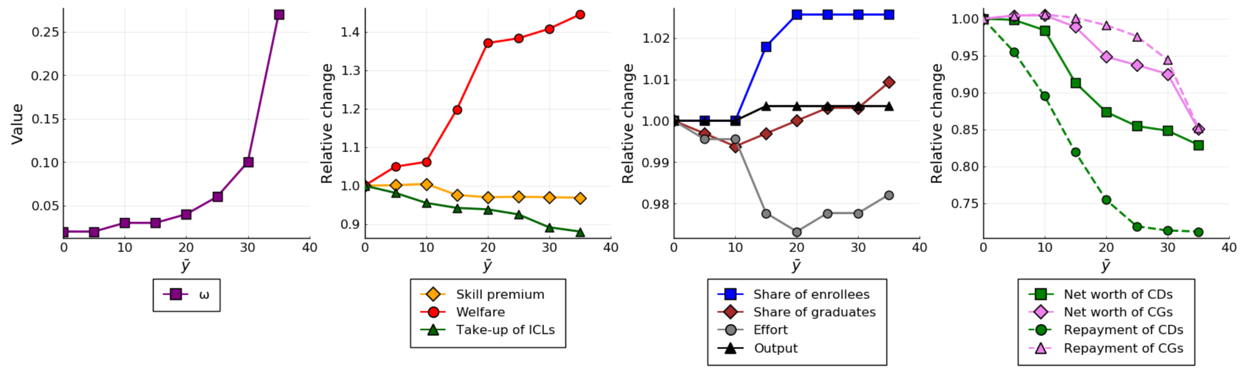

Figure 5: Economic implications of varying parameters of ICLs

Note: $\bar{y}$ stands for poverty threshold, as in (16), 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 $\bar{y} = 0$ and $\omega = 5\%$.

Varying Parameters of ICLs

After having demonstrated that the current design of ICLs in the US significantly improves overall welfare, we follow up with a broader investigation of the interaction between the ICL design and social welfare. In particular, we conduct a comparative statics exercise of the ICL system by holding the repayment period $\bar{T}$ fixed and varying both the poverty threshold $\bar{y}$ and the statutory repayment rate ω (see equation (16)). We do this in a way that the expected impact of the reform on the government's budget is approximately neutral, i.e. such that the following relationship holds:

$$\omega(y_{mean} - \bar{y}) = \omega_{US}(y_{mean} - \bar{y}_{US}) \tag{17}$$

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 "repayment-relevant" college dropouts and graduates, i.e. of those individuals with discretionary income above the poverty threshold and below the maximum repayment limit.

Thus, once we choose $\bar{y}$, equation (17) determines the value of ω. 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 exact ω balancing the (ex-post) budget constraint turns out to be not viable due to the possibility of multiple equilibria.[32]

[32] For a given value of $\bar{y}$, we may have multiple equilibria. This is the case since balancing the government budget may be possible with multiple values of ω as it effectively pins down incentives for exerting educational

Figure 5 presents the main results of our investigation, with further details on other statistics being relegated to Table 9 in Appendix G. Interestingly, we find that poverty threshold $\bar{y}$ is an important determinant of the effectiveness of ICLs. As there are few individuals with gross earnings below $10,000, the economy's response to ICLs $\bar{y}$ in that region is rather mild. For example, for $\bar{y} = 0$ the welfare impact of ICLs on newborns amounts to only 0.81%. However, when the insurance for people below the poverty threshold is increased (as $\bar{y}$ increases), we observe significant welfare gains for newborn population. Because increases in $\bar{y}$ reduce the mean repayments and also the severity of dropout risk, college enrollment and student borrowing increase. From the aggregate economy perspective, this leads to reductions in the skill premium. Moreover, the share of population benefiting from ICLs declines in $\bar{y}$ because the associated increases in ω imply that indebted agents hit the repayment limit faster.

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 (both the direct one and the one stemming from reductions in the skill premium). However, for higher levels of $\bar{y}$ the educational effort starts increasing as repayments between graduates and dropouts start getting closer to each other at a faster pace, increasing the relative value of becoming a graduate (everything else held constant). Finally, the share of graduates follows a similar U-shaped pattern as it is a product of both the college enrollment and educational effort.

Overall, our results show that the non-linear structure of ICLs is an important element enhancing the effectiveness of the student loan system in the US. As individuals with low labor income make lower repayments (if any), increases in $\bar{y}$ bring the idea of providing financial aid through ICLs closer to the means-tested education subsidies. However, an important difference here is that providing financial aid through loans may be much easier to implement politically as they are tied to the actual labor market experiences of borrowers.

6 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.

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 Laffer curve).

In this paper, we evaluate both theoretically and empirically the impact of ICLs in an environment with uninsurable college graduation and income risks, and moral hazard generated by unobservability of educational effort. The latter component induces an important trade-off: any gains from higher educational participation can potentially be off-set by a reduction in incentives for exerting effort. To this end, we first develop a simple theoretical model of college enrollment with educational effort affecting students' prospects of graduation. Within this framework, we show that the enrollment in the laissez-faire allocation is inefficiently low due to the uninsurable risk of dropping out, as compared with the second best allocation providing insurance for this risk. At the same time, however, the laissez-faire level of educational effort is higher than that in the second best because of the moral hazard resulting in a equity-efficiency trade-off. Then, we show that that the second best allocation can be implemented using an integrated system of ICLs and income taxes. This shows that ICLs can be welfare-improving, but also that they come with an important trade-off: they stimulate increases in college enrollment, but also reduce incentives for students to provide educational effort.

In the second part of the paper, we extend the theoretical framework developed into a rich life-cycle overlapping generations heterogeneous agents economy, with relevant general equilibrium effects, incomplete markets and intergenerational linkages. Using various sources of micro-data, we calibrate our experimental economy to the context of the US economy. Our quantitative analysis shows that the current design of ICLs in the US brings a significant welfare improvement equivalent to a 1.14% increase in permanent consumption. In our next exercise, we investigate the welfare implications of varying the key parameters of ICLs in the US: the share of income devoted to student loan repayments and the poverty threshold introducing no-repayment regions for individuals with particularly low earnings. It turns out that a high enough level of the poverty threshold is essential to ensuring high effectiveness of ICLs, as it significantly improves the targeting of insurance to the actually struggling individuals.

Finally, in spite of the general richness of our experimental 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 Theoretical appendix

This appendix contains proofs of all theoretical results in the paper.

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

$$\begin{aligned}
&\mathrm{c}_{HS}^{SB}: \ u'\left(c_{HS}^{SB}\right)(\Phi-\psi_\Phi)=\mu\Phi\\
&\mathrm{c}_{CD}^{SB}: \ u'\left(c_{CD}^{SB}\right)\left[(1-p(h_e))((1-\Phi)+\psi_\Phi)-\psi_e p'(h_e)\right]=\mu(1-\Phi)(1-p(h_e))\\
&\mathrm{c}_{CG}^{SB}: \ u'\left(c_{CG}^{SB}\right)\left[p(h_e)((1-\Phi)+\psi_\Phi)+\psi_e p'(h_e)\right]=\mu(1-\Phi)p(h_e)\\
&\mathrm{h}_e^{SB}: \ \mu(1-\Phi)p'(h_e)\boldsymbol{\Delta}_{graduate}=\psi_e\left\{v''(h_e)-p''(h_e)\left(u\left(c_{CG}^{SB}\right)-u\left(c_{CD}^{SB}\right)\right)\right\}\\
&\Phi: \ \mu\boldsymbol{\Delta}_{enroll}=\psi_\Phi(b-a)
\end{aligned}$$

where

$$\boldsymbol{\Delta}_{graduate}=(w_{CG}-c_{CG}^{SB})-(w_{CD}-c_{CD}^{SB})$$

$$\Delta_{enroll}=\left[p(h_e)\left(w_{CG}-c_{CG}^{SB}\right)+(1-p(h_e))\left(w_{CD}-c_{CD}^{SB}\right)-(1+r)\varphi\right]-(w_{HS}-c_{HS}^{SB})$$

and ψ_e, ψ_Φ and μ denote the Lagrange multipliers on the enrollment (7), incentive compatibility (8) and resource (5) constraints, respectively.

Proof 1 *First, notice that the objective function is equivalent to:*

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

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

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

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

after applying the effort incentive compatibility constraint (8) and rearranging terms.

The enrollment first order condition follows from:

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

after applying the enrollment constraint (7) and rearranging terms.

Lemma 2. *Second best allocation is characterized by partial insurance against the dropout risk.*

Proof 2 *We first show that the amount of insurance provided is positive, i.e. that $c_{CG}^{SB} - w_{CG} < w_{CD}^{SB} - w_{CD}$. Assume otherwise: $c_{CG}^{SB} - w_{CG} \geq w_{CD}^{SB} - w_{CD}$. Because $w_{CG} > w_{CD}$, this implies that $c_{CG}^{SB} > c_{CD}^{SB}$. Given inequality (9), we infer from the effort first order condition that it must be that $\psi_e \leq 0$. If $\psi_e = 0$, then $c_{CG}^{SB} = c_{CD}^{SB}$ from the consumption first order condition. If $\psi_e < 0$, $u'(c_{CG}^{SB}) > u'(c_{CD}^{SB}) \Rightarrow c_{CG}^{SB} < c_{CD}^{SB}$. 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 incentive compatibility constraint (8), $h_e = 0$ 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.

Proposition 1. *The competitive equilibrium with the following joint system of (i) income tax for high school graduates, and (ii) income-contingent student loan repayment rates attains the second best allocation:*

$$\tau_{HS} = 1 - \frac{c_{HS}^{SB}}{w_{HS}} \tag{18}$$

$$\varphi_{CD} = \frac{w_{CD} - c_{CD}^{SB}}{1 + r} \tag{19}$$

$$\varphi_{CG} = \frac{w_{CG} - c_{CG}^{SB}}{1 + r} \tag{20}$$

where c_{HS}^{SB}, c_{CD}^{SB}, c_{CG}^{SB} are the second best consumption allocations of CG, CD and HS. Furthermore, this allocation satisfies the following government budget balance condition:

$$\Phi \tau_{HS} w_{HS} = (1 - \Phi) \left[p\left(h_e^{dec}\right) \varphi_{CG} + \left(1 - p\left(h_e^{dec}\right)\right) \varphi_{CD} - \varphi \right] \tag{21}$$

Proof 3 *The optimal repayment and tax rates can be found by equating:*

$$c_{HS}^{SB} \overset{!}{=} c_{HS}^{dec} = w_{HS}\left(1-\tau_{HS}\right)$$
$$c_{CD}^{SB} \overset{!}{=} c_{CD}^{dec} = w_{CD}-\left(1+r\right)\varphi_{CD}$$
$$c_{CG}^{SB} \overset{!}{=} c_{CG}^{dec} = w_{CG}-\left(1+r\right)\varphi_{CG}$$

where $c_e^{SB},\ i \in \{HS, CD, CG\}$ *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 second best and income tax-ICL allocations, we automatically have that* $h_e^{SB} = h_e^{dec}$*, and as a consequence* $\bar{\chi}^{SB} = \bar{\chi}^{dec}$*. Checking budget balance:*

$$\begin{aligned}\left(1-\bar{\chi}\right)\left(1+r\right)\left[p\left(h_e\right)\varphi_{CG}+\left(1-p\left(h_e\right)\right)\varphi_{CD}\right]-\bar{\chi}\tau_{HS}w_{HS} &= \\ \left(1-\bar{\chi}\right)\left(1+r\right)\left[p\left(h_e\right)\left(w_{CG}-c_{CG}^{SB}\right)+\left(1-p\left(h_e\right)\right)\left(w_{CD}-c_{CD}^{SB}\right)\right]-\bar{\chi}\left(1-\frac{c_{HS}}{w_{HS}}\right)w_{HS} &= \\ \left(1-\bar{\chi}\right)\left(1+r\right)\varphi\end{aligned}$$

where in the last step we have used resource constraint in second best. This proves the decentralization.

Proposition 2. *There exist policy instruments* $\tau_{HS} = 0$ *and* φ_{CD} *and* φ_{CG} *implementing as a competitive equilibrium the second best allocation* SB' *subject to additional constraint* $c_{HS}^{SB'} = w_{HS}^{SB'}$*. 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 4 *Denote by* SB' *the problem akin to second best allocation with the additional constraint of* $c_{HS}^{SB'} = w_{HS}$*. The first claim can be shown easily by applying the logic of Proposition 1 to the first order conditions as in Lemma 1 (adjusted for the constraint* $c_{HS}^{SB'} = w_{HS}$*), and following steps in Lemma 2.*

For the second claim, assume the opposite, i.e. that $V^{enroll,CE} \geq V^{enroll,SB'}$*. 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 CE 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* $V^{enroll,CE} - V^{enroll,SB'} \geq 0$.

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 CE, everything that is achievable in CE is achievable in SB'. Following steps similar to the ones in Lemma 2 we can show that the SB' is characterized by partial insurance, i.e. it follows that the SB' allocation is different than the CE one. Because SB' is characterized by partial insurance, and in particular we have that $c_{CD}^{SB'} > w_{CD}$*, it follows that the SB' allocation is not attainable under CE. 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 (8), this implies that* $h_e^{SB'} < h_e^{LF}$*.*

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* $c_j(\boldsymbol{s}_j)$, $a'_j(\boldsymbol{s}_j)$, $h_{\ell,j}(\boldsymbol{s}_j)$, $b(\boldsymbol{s}_j)$, $c_j^c(\boldsymbol{s}_j^c)$, $a_j'^c(\boldsymbol{s}_j^c)$, $h_{\ell,j}^c(\boldsymbol{s}_j^c)$, $h_{e,j}^c(\boldsymbol{s}_j^c)$, $d_j(\boldsymbol{s}_1^c)$ *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.*

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

where

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

and

$$y_j(\boldsymbol{s}_j) = w^e \epsilon_j^e(\theta,\eta) h_{\ell,j}(\boldsymbol{s}_j)$$
$$y^c(\boldsymbol{s}^c) = w^U \epsilon_1^U(\theta,\eta) h_{\ell,j}^c(\boldsymbol{s}_j^c)$$

4. *Labor and asset markets clear.*

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

$$H^U = \sum_{j=2}^{j_r-1} \int_{S_j^{CD}} \epsilon_j^{CD}(\theta,\eta) h_{l,j}(\boldsymbol{s}_j) d\mu_j^{CD}$$
$$+ \sum_{j=1}^{j_r-1} \int_{S_j^{HS}} \epsilon_j^{HS}(\theta,\eta) h_{l,j}(\boldsymbol{s}_j) d\mu_j^{HS} + \int_{S_1^c} \epsilon_1^{HS}(\theta,\eta) h_{l,1}^c(\boldsymbol{s}_1^c) d\mu_1^c + \int_{S_2^c} \epsilon_1^{CD}(\theta,\eta) h_{l,2}^c(\boldsymbol{s}_2^c) d\mu_2^c$$

and

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

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. We 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, 2015]. 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).[33] 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 of 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 6. 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.[34]

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. [Chamberlain, 1984]) on moments including covariances of residuals at different age-lags (for age 25 to

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

[34] 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 6: Age profile estimates of each education level

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

39). This procedure gives us estimates of persistence ρ^e, the variance of the residual σ^e_η, 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^e_θ, 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 of the NLSY79 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.[35] We exclude children with missing PIAT math scores, leaving us with 9,232 children born to

[35] 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 7: 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	Fixed	ICL
Welfare		
Average cons.-eq. welfare gain		+1.18%
Average cons.-eq. welfare gain for HS		-0.23%
Average cons.-eq. welfare gain for CD		+1.60%
Average cons.-eq. welfare gain for CG		+1.90%
Education sector		
Share of college enrollees	74.7%	77.2%
Share of college graduates	31.7%	32.7%
Skill premium	90.7%	86.3%
Share of time studying	22.4%	22.3%
Mean ability of enrollees	5.144	5.139
Mean parental transfer	$37,139	$36,604
Average net worth of CG	-$4,759	-$7,793
Average net worth of CD	$6,326	$4,606
Average net worth of HS	$22,864	$24,318
Borrowers qualifying for ICLs	N/A	47.8%
Mean repayment by CG	$2,063	$1,313
Mean repayment by CD	$978	$489
Labor income tax rate	35.3%	35.6%
Production sector		
Aggregate output	0.282	0.283
Aggregate capital	0.383	0.383
Interest rate r	5.4%	5.4%
Labor hours of CG	36.6%	35.7%
Labor hours of CD	33.3%	33.1%
Labor hours of HS	31.7%	31.6%

Table 8: Aggregate statistics of economies without and with ICLs and with perfect substitution between skill types

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 (USD11,500 for CDs and USD 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).

Statistic	$\bar{y} = \$0$	$\bar{y} = \$10,000$	$\bar{y} = \$20,000$	$\bar{y} = \$30,000$	$\bar{y} = \$35,000$
Repayment rate ω	2%	3%	4%	10%	27%
Welfare					
Average cons.-eq. welfare gain	+0.81%	+0.86%	1.11%	+1.14%	+1.17%
Average cons.-eq. welfare gain for HS	+0.21%	+0.13%	+0.17%	+0.12	+0.11 %
Average cons.-eq. welfare gain for CD	+1.31%	+1.50%	+1.88%	+1.95%	+1.94%
Average cons.-eq. welfare gain for CG	+0.79%	+0.84%	+1.01%	+1.11%	+1.30%
Education sector					
Share of college enrollees	78.0%	78.0%	80.0%	80.0%	80.0%
Share of college graduates	32.3%	32.1%	32.3%	32.4%	32.6%
Skill premium	86.7%	87.1%	84.1%	84.1%	84.0%
Share of time studying	22.4%	22.3%	21.8%	21.9%	22.0%
Mean ability of enrollees	5.138	5.138	5.134	5.134	5.134
Mean parental transfer	$37,473	$37,355	$37,296	$37,274	$37,170
Average net worth of CG	-$6,945	-$6,912	-$7,302	-$7,464	-$7,983
Average net worth of CD	$5,363	$5,280	$4,686	$4,550	$4,447
Average net worth of HS	$26,373	$26,296	$28,716	$28,696	$28,590
Borrowers qualifying for ICLs	53.7%	51.3%	50.4%	47.9%	47.3%
Mean repayment by CG	$1,399	$1,407	$1,387	$1,321	$1,192
Mean repayment by CD	$697	$624	$526	97	$496
Labor income tax rate	36.0%	36.0%	36.0%	36.0%	36.1%
Production sector					
Aggregate output	0.284	0.284	0.285	0.285	0.285
Aggregate capital	0.379	0.379	0.381	0.381	0.381
Interest rate r	5.6%	5.6%	5.5%	5.5%	5.5%
Labor hours of CG	35.7%	35.6%	35.5%	35.3%	35.0%
Labor hours of CD	32.6%	32.5%	32.5%	32.6%	32.7%
Labor hours of HS	31.2%	31.2%	31.1%	31.1%	31.1%

Table 9: Aggregate statistics of economies without and with ICLs

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.

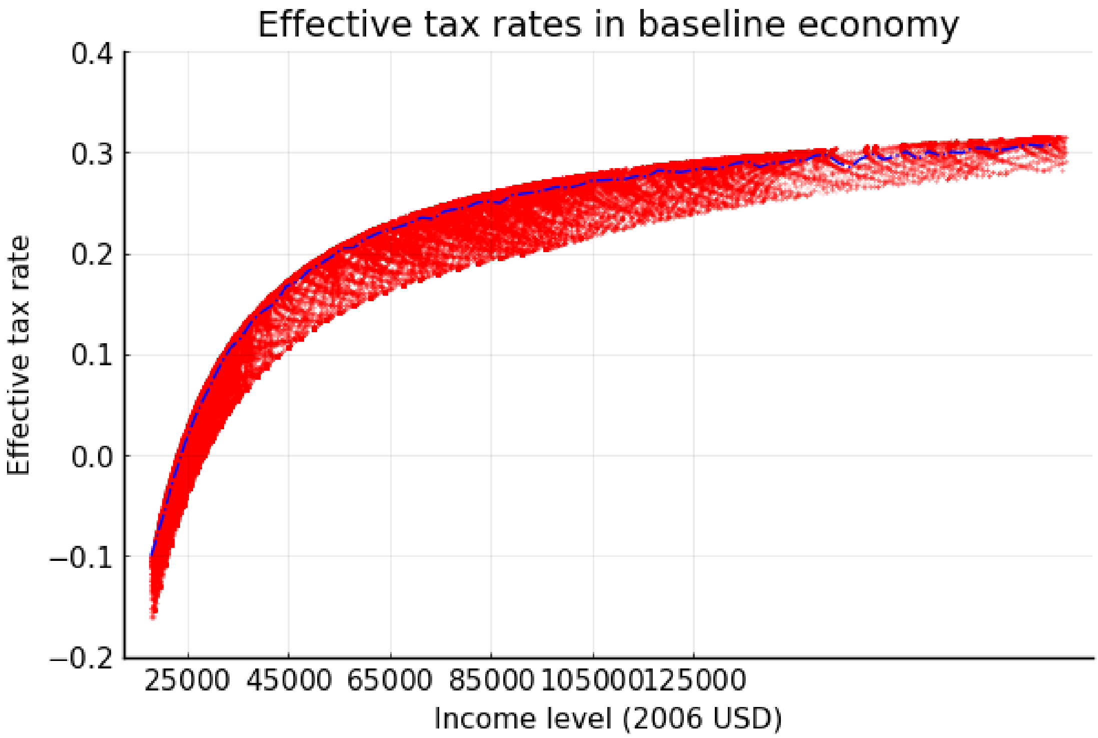

Figure 6: Effective income tax mean and distribution

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).

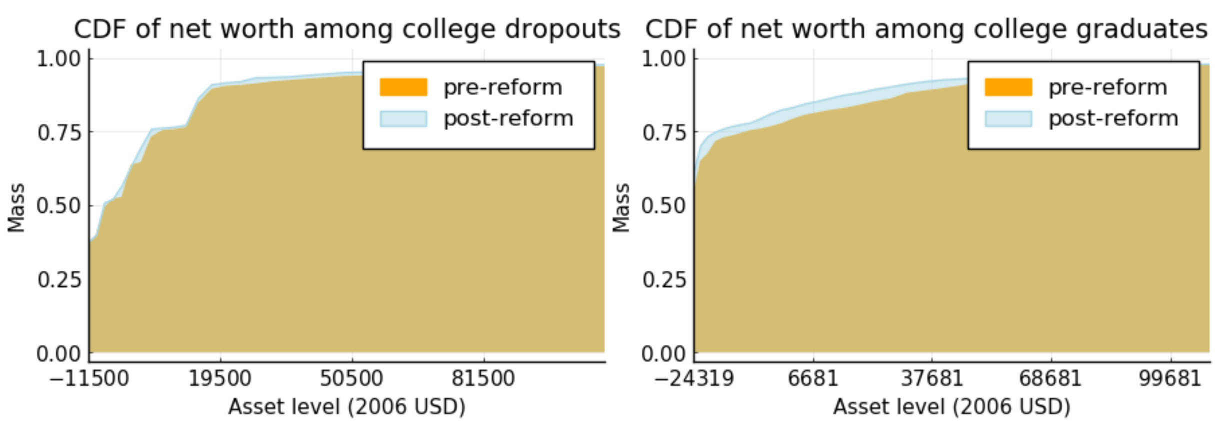

Figure 7: Cumulative distribution of net worth for college dropouts and graduates

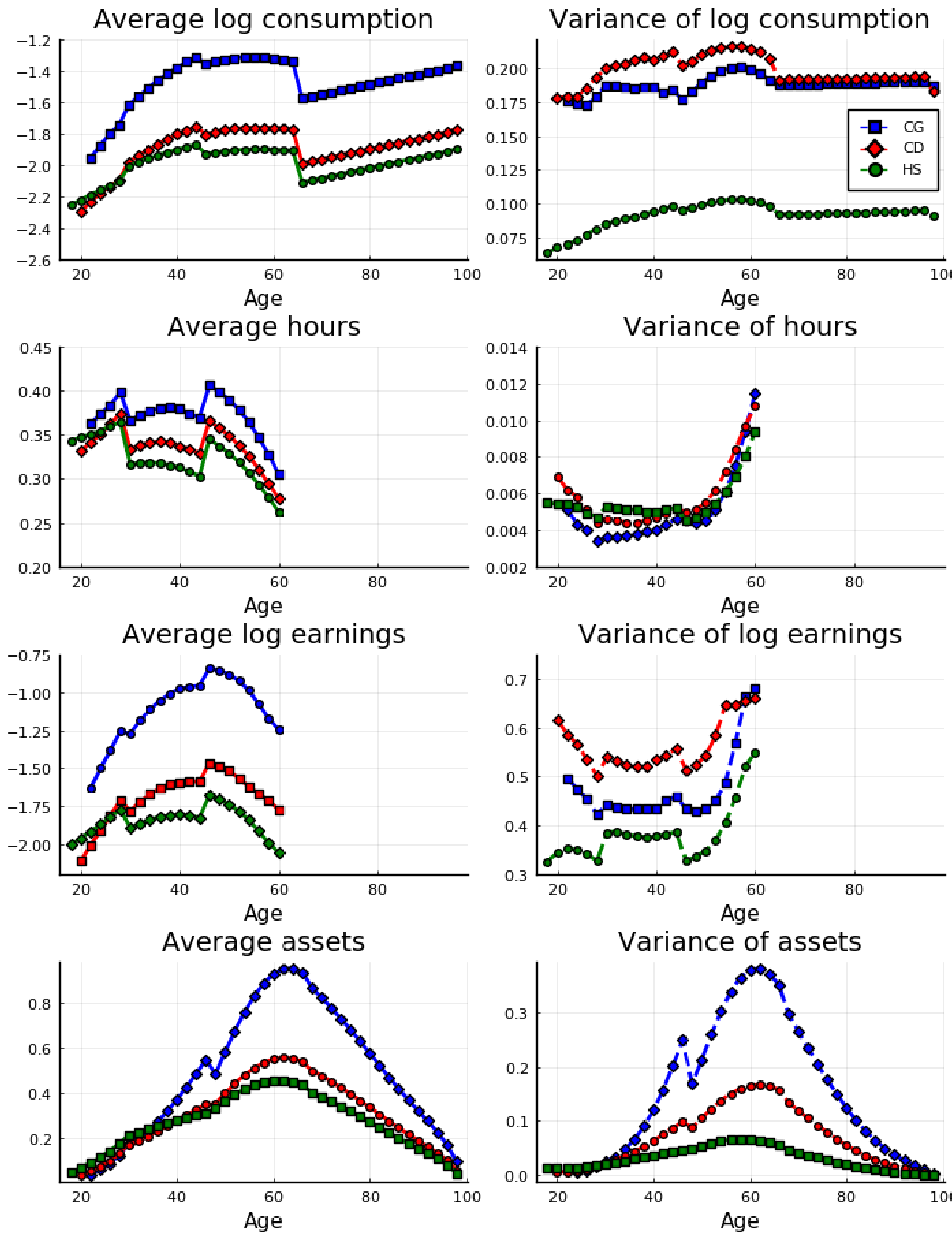

Figure 8: Life-cycle profiles by education

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.