Higher Education Funding, Welfare and Inequality in Equilibrium ☆

Gustavo Mellior[a]

Abstract

This paper analyses quantitatively the effect that higher education funding policies have on welfare and inequality. We evaluate five different higher education financing schemes with a heterogeneous agent model in continuous time. When educational costs are small, differences in outcomes across systems are negligible. As the cost of education and the share of debtors in society rises, it becomes preferable to fund education with subsidies, instead of student loans, as there is a pecuniary externality that arises with debt. Although subsidies can generate large steady state welfare gains, transition costs can be large enough to justify the status quo. The exception, full subsidy with graduate taxes, yields substantial welfare gains, even when taking into account transitional dynamics.

Keywords: Incomplete markets, Higher education funding, Human capital
JEL Classifications: D52, D58, E24, I22, I23

☆I would like to thank two anonymous referees, Ruben Enikolopov, Eric Brousseau, Jens Prufër, Benjamin Moll, Oliver de Groot, Miguel León Ledesma, Jesús Fernández Villaverde, Rick van der Ploeg, Hamish Low, Ken Mayhew, Katsuyuki Shibayama, Esteban Ortiz-Ospina, Catalina Granda, Xiaowen Lei, Keisuke Otsu, Elizabeth Caucutt, Francesco Lippi, Anna-Maria Tkhir, and seminar participants at The Oxford Macro lunch, Aix-Marseille School of Economics, Social Inequality Research Group at Nuffield College, Money Macro Finance PhD Conference, Bank of England, Royal Economic Society Annual Conference 2021, Society for Economic Dynamics 2021 Annual Conference, EALE 2021 Annual Conference, Econometric Society-LACEA-LAMES 2021 Conference, UDEA, Liverpool Economics of Education Workshop, Scottish Economic Society 2022 Annual Conference, Institute for Fiscal Studies, 2023 EU Commission Annual Research Conference and Kent MaGHiC for useful comments and suggestions.

[a] University of Liverpool, Chatham Rd, L69 7ZH, UK. Corresponding author. g.mellior@liverpool.ac.uk

1 Introduction

Student debt is now the second largest type of household debt in the United States, recently surpassing 1.7 trillion dollars. As shown in Fig. 1, the average student at an American university graduates with over $34,000 of debt, while the total stock of student debt has recently reached 8% of all personal disposable income. According to the Institute for Fiscal Studies and the Sutton Trust, the average UK student graduates with over £44,000 worth of debt (Kirby (2016)). The rising costs of higher education and concerns surrounding student indebtedness have intensified calls for policies such as student loan forgiveness and/or free tuition at public universities. Critics of these policies contend that they are regressive. They argue that, since the benefits of higher education primarily accrue to the individual obtaining a degree, while the costs are borne by taxpayers, many of whom do not derive such benefits, these measures may exacerbate inequality rather than ameliorate it.

Income-contingent student loans have been proposed as an efficient solution for financing tertiary education. They increase access to higher education for low-income households by reducing capital market imperfections in educational investments and mitigating income uncertainty through protections against adverse economic shocks. Leading advocates of income-contingent student loans argue that this approach best balances equity and efficiency trade-offs, is the 'most efficient' and that 'tax funding (of higher education) is unfair' (Barr and Crawford (2000)).[1]

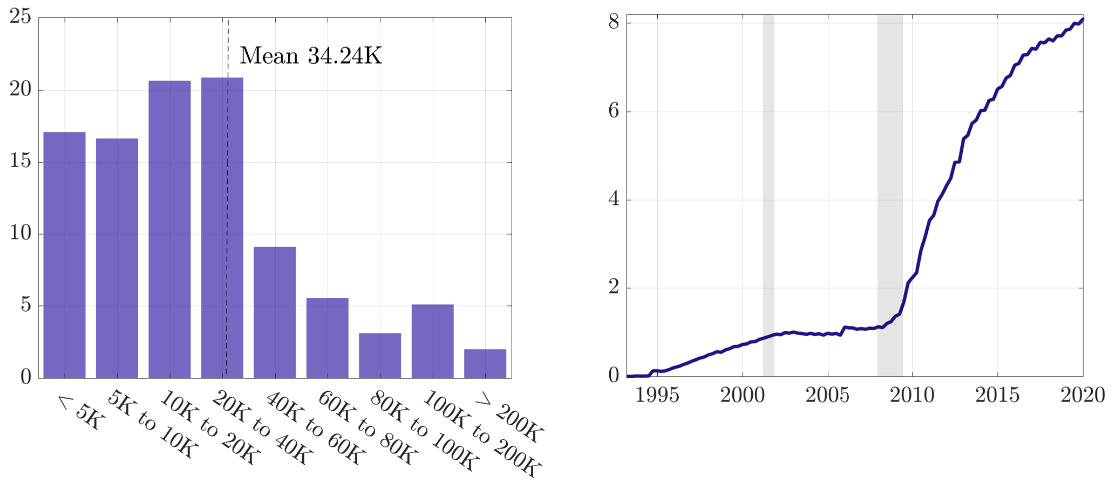

Fig. 1: Left: % of borrowers by student loan balances at the 2nd quarter of 2020. Source: U.S. Department of Education. Right: Federal student debt as a percentage of disposable personal income. Source: BEA and Board of Governors.

There are considerable reasons to question whether this should be the preferred approach to financing tertiary education. First, while there appears to be a broad consensus, undisputed in some policy circles, on the use of income-contingent loans to finance higher education, there is no single, universally preferred policy for financing higher education within the OECD.[2] In reality, considerable variability exists, as illustrated in Fig. 2. Second, larger public spending in higher education relative to GDP is associated with lower income inequality in the OECD (see Fig. 28 in the appendix and Holter (2015)). Finally, and central to this article, a body of research in

[1] *'(income-contingent student debt) is efficient, in that it addresses the major capital market imperfection... It is fair, because people with low earnings make low repayments and people with low lifetime earnings do not repay their loan in full... tax funding (of higher education) is unfair.'*

[2] The same can be said of economists working on this field of research. There is no consensus on the optimal method of financing higher education. Even within the small subset of the literature cited below, policies such as graduate taxes, tuition subsidies, merit grants, or income-contingent loans appear to be the preferred policy choice.

heterogeneous-agent macroeconomics demonstrates that agents' savings behaviour can generate pecuniary externalities that steer the economy away from efficiency (Aiyagari (1994), Obiols-Homs (2011), Dávila et al. (2012), Nuño and Moll (2018) and Angelopoulos et al. (2017)). It is not clear a priori whether a higher education financing system relying on student loans, on tuition subsidies, or on graduate taxes exacerbates these externalities by incentivising under- or over-accumulation of human and physical capital.

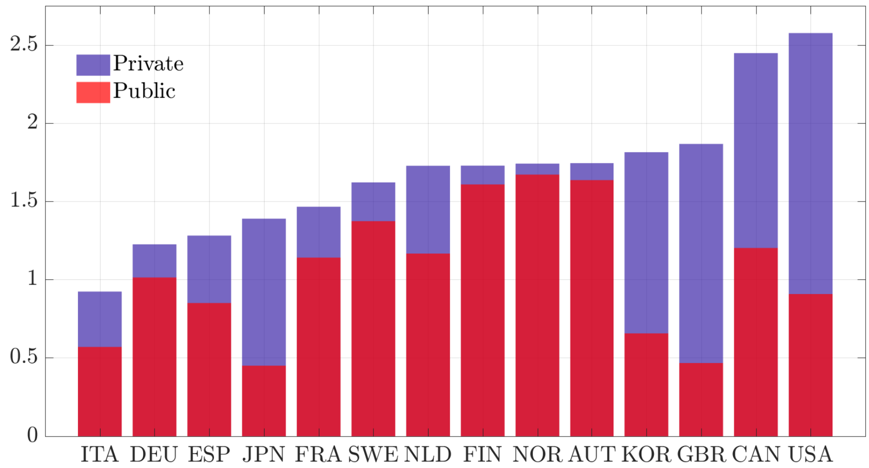

Fig. 2: Public and private expenditure on tertiary education relative to GDP in 2015. Source: OECD.

In this paper we evaluate the welfare and distributional outcomes of five different higher education financing schemes, using a heterogeneous agent model in continuous time, following Nuño and Moll (2018), extended to allow endogenous educational choices, intergenerational transmission of educational skills and early repayment of student loans. This allows us to evaluate the impact that the most salient features of various educational systems (American, Continental European and that of England and Wales) have on welfare and inequality. We calibrate the baseline to the United States, where the government provides a student loan facility and partially subsidises the cost of education. In this system, student loans lack income-contingent features, meaning that borrowers must repay their loans regardless of their income levels. We then introduce two variants that incorporate income-contingent protections, illustrating how even minor adjustments in the design of such schemes can lead to significantly different outcomes. Finally, in the last two regimes the government provides support exclusively with tuition subsidies that may cover fully or partially the cost of education; the difference is whether they are funded through general taxation or graduate taxes.

The main contribution of this paper is showing that the rankings among systems in terms of welfare and inequality depend on the cost of education. When educational costs are small, differences in outcomes across systems are negligible. However, as education costs rise to realistic values, income-contingent loans and subsidies become more attractive ways to finance tertiary education, with the latter yielding the largest welfare gains and reductions in inequality, especially when coupled with graduate taxes. The role of costs has been largely neglected in prior research and it is particularly relevant in light of rising education costs. For example, in the United States, these costs have consistently grown faster than the CPI and those of housing and healthcare (see Fig. 29 in the appendix). Although tertiary education costs in Europe have not escalated as rapidly, several countries are experiencing notable increases (see Fig. 30 and Fig. 31 in the appendix). Another contribution of this study is the assessment of the financing of tertiary education under the lens of *the price and quantity effects of debt*, linking welfare to borrowing limits, debtor shares, and higher education financing.[3] This study demonstrates that the pecuniary externalities arising from agents' savings decisions, as described in Obiols-Homs (2011), remain significant in environments with both physical and human capital. Systems that deliver large shares of the population as net debtors tend to have more inequality and lower welfare. Additionally, our model's ability to accommodate many different higher education financing schemes, contributes by allowing us to draw robust comparisons across five different financing regimes.

Using general equilibrium steady state and transition comparisons, aggregate and individual measures of welfare and a large sensitivity analysis we show that results are affected by two forces: 1) *the shape of the endogenous distribution of income and wealth* and 2) *the price effects of debt* described in Obiols-Homs (2011). We show that subsidies, as opposed to loans, generate wealth distributions with smaller amounts of the population as net debtors. Additionally, the equilibrium interest rate ends up being higher, which rewards a society with relatively more lenders. Moreover, equilibria with higher net debtor shares tend to be associated with larger wealth inequality. Tuition subsidies place relatively larger shares of the population in the graduate labour market. These distributional impacts have an influence on welfare rankings and in the public cost of higher education. For instance, depending on its design, the fiscal burden of the student loan system may exceed that of tuition subsidies. By disaggregating welfare gains across wealth, income, and ability groups, we identify who benefits and who loses from higher education financing reforms and how they shape broader fiscal and distributional outcomes.

This article emphasises the importance of evaluating the transitional dynamics of policy changes. While we show substantial steady state gains in terms of consumption equivalent variation of different higher education systems, large transition costs from one regime to another may justify the status-quo. For example, moving from the baseline to a subsidised system financed by graduate taxes (the system yielding the largest transition welfare gains) can be costly enough to offset more than 60 % of the steady state welfare gains. By comparison, a subsidised system financed by general taxation, which delivers slightly larger steady-state gains than graduate taxes, loses all of its welfare gains when we take into account transition costs. As a consequence, steady state comparisons of different higher education systems may be misleading for policy.

Related literature: A substantial body of work lies at the intersection of macroeconomics, education financing and its distributional impact - García-Peñalosa and Wälde (2000), Bénabou (2002), Hanushek et al. (2003), Bovenberg and Jacobs (2005), Dearden et al. (2008), Johnson (2013), Herrington (2015), Cai and Heathcote (2018) and Luo and Mongey (2019). The studies most closely related to this paper include Ionescu and Simpson (2016), Krueger and Ludwig (2016), Abbott et al. (2019), Hanushek et al. (2014) and Heijdra et al. (2017). Ionescu and Simpson (2016) find results consistent with those presented here, using a life-cycle framework: tax-financed grants can have a greater impact on improving welfare than increasing student loan limits, particularly when such limits are already large. The present study adds to their results in two ways: endogenising the risk free equilibrium interest rate and factoring transition costs. As will be shown, it is not enough to demonstrate that one regime is better than another, the costs of transition must also be taken into account as they can be large enough to significantly lessen the desirability of higher education reforms.

Krueger and Ludwig (2016) explores transitions within the context of optimal taxation and

[3] Obiols-Homs (2011), shows that too lax borrowing constraints may drag down aggregate welfare. When society has a large fraction of net debtors, the beneficial *quantity effect* of large debt limits (because individuals can continue to optimise and smooth consumption with debt), can be overwhelmed by the *price effect* of more debtors putting upward pressure on the interest rate. Similar effects are major forces driving welfare and efficiency in heterogeneous agent models (Dávila et al. (2012) and Nuño and Moll (2018)).

education finance. Building on their findings, our analysis extends the discussion in several key ways. First, our baseline economy incorporates a broader range of higher education financing options, including a mix of government-backed and private loans with varying repayment terms. This approach enables us to systematically compare different higher education financing systems, several of which have received limited attention in the existing literature. Moreover, we abstract from optimal taxation, so that we can see how results go through even with a flat tax, as a popular concern against tax-based financing of higher education is that it can be regressive and that in turn, it may reinforce inequality. Abbott et al. (2019) address questions similar to those in this study using a detail-rich life-cycle model. Their findings indicate that merit-based grants and the current U.S. student loan system yield significant welfare gains. However, their focus on specific features of the U.S. student loan programme leaves room for further exploration of alternative financing schemes, which we undertake in this study. Hanushek et al. (2014) and Heijdra et al. (2017) examine various higher education funding schemes with overlapping generations models. While their findings align with some of our results, we extend their analysis by introducing additional variations of income-contingent loan programmes and graduate taxes, as well as by examining more disaggregated welfare measures. We also conduct an extensive sensitivity analysis to highlight how the pecunairy externalities described in Obiols-Homs (2011) and Nuño and Moll (2018) influence results. In addition, we assess the impact of education costs on the different outcomes of various tertiary education financing schemes.

Finally, the model developed herein contributes to the literature on debt limits and welfare, confirming the presence of price and quantity effects in environments with two types of debt and the simultaneous presence of physical and human capital. For instance, this paper expands on Angelopoulos et al. (2017), who study the pecuniary externalities arising from agents' different savings policies, which vary by education and income profiles. Whereas Angelopoulos et al. (2017) fix exogenously the agent types and restricts flows between groups, this paper endogenises such flows through optimal education choice and evaluates how different higher education systems affect the composition of types in society. Additionally, this work complements findings in Caucutt and Lochner (2020), deepening our understanding of how borrowing constraints affect educational investments not only through the dynamic complementarity of early and late life investments in education, but through price and distributional effects as well.

This paper is structured as follows. In Section 2 we describe the model. In Section 3 we show steady state comparisons of the different higher education financing schemes, where we evaluate welfare gains from each regime, from aggregate and disaggregated perspectives and carry out a sensitivity analysis. In Section 4 we analyse whether it is worth transitioning from one higher education system to another, specifically from a benchmark towards any of the alternatives considered in this paper. In Section 5 we consider the policy relevance of results in the context of European institutions. The sixth section concludes.

2 Model

2.1 Agents

The model builds on Nuño and Moll (2018). Time is continuous and agents live in a perpetual youth environment.[4] There is a continuum of unit measure of agents that are ex-ante identical

[4]While a perpetual youth framework may omit certain trade-offs intrinsic to a life-cycle approach, it enables a richer modelling of higher education systems in other dimensions. For example, it simplifies the computation of transitions and including features such as tracking the distribution of student loans and the endogenous early repayment of student debt. Incorporating these features in a life-cycle approach would introduce significant computational complexities that constrain the scope of the policy experiments considered in this paper. In Sections 3 and 4, we consider how a perpetual youth framework may bias results relative to a life-cycle approach.

(except for their innate ability to graduate from university m) and ex-post heterogeneous in their income, wealth, education status and employment state. Lifetimes are random and follow an exponential distribution with a mean value of $\frac{1}{\kappa}$. The size of the population is constant; when an agent dies it is replaced by a new one that inherits its wealth.[5] All new agents are born unemployed and without a college degree.[6] The "parent's" education status and educational ability influence whether the offspring will be born with high or low educational ability, as in Abbott et al. (2019).

Agents discount utility flows from consumption, c_t, and bequests, q_t at rate ρ.[7] They have CRRA preferences over utility flows from consumption described by $u(c_t) = \frac{c_t^{1-\sigma}}{1-\sigma}$, where $\sigma > 0$. Agents can save by accumulating wealth, b, (a negative value of b means an agent is in debt). There is an exogenous debt limit, $\underline{b}$, such that $b_t \geq \underline{b}$, where $-\frac{z_{u,NC}}{r} < \underline{b} < 0$ and r is the risk free interest rate.[8] When we introduce government guaranteed student loans, a, agents will be able to finance the cost of higher education (HE) with both a and b. There is also a finite debt limit on student loans, $\underline{a}$, not to be confused with the lower limit of the state space in the student loans dimension, $\underline{\underline{a}}$.[9] q is defined as $\hat{\phi}\mathbb{E}_m V(z_{u,NC}, b\mathbb{1}_{\{b\geq 0\}}, 0, m)$, where $\hat{\phi}$ is a parameter capturing how much parents care for the newborn's value function, V, and where m is the ability type of the newborn. The first argument of V in q indicates that all agents are born as unemployed non-graduates. The second and third arguments specify that all agents are born with non-negative wealth b and no student loan balances. A higher likelihood of having a high-ability child increases the utility derived from bequests.

The mass of agents with ability type m is divided into three broad groups: students, non-graduates, and graduates. The latter two groups are further subdivided into employed and unemployed agents. Fig. 3 illustrates how agents within an ability level m move between the five possible types: $\theta^m_{u,NC}$ unemployed and no college degree, $\theta^m_{e,NC}$ employed and no college degree, θ^m_s student, $\theta^m_{u,C}$ unemployed college graduate and $\theta^m_{e,C}$ employed college graduate. The superscript $m \in \{H, L\}$ is the ability type. The transition rates are denoted with subscripts indicating the origin and destination. For example, $\lambda_{ue,NC}$ represents the transition rate for non-graduates moving from unemployment to employment.

Agents can invest in education if they find it optimal to do so and can afford its cost. Education is risky; it takes four years on average to graduate, there is a college dropout risk, captured by λ^S_x, that depends on the agent's innate ability and there is no guarantee that agents will find a job once they graduate. A college degree increases the labour earnings potential of agents and places them in a more favourable labour market.[10]

The flows from non-graduates to students are endogenous. The transition rates λ^U_x and λ^E_x represent the rate at which a college degree depreciates, capturing how technological advances render certain careers, previously requiring tertiary education qualifications, redundant.[11] Moreover, $\lambda^U_x > \lambda^E_x$, reflects how unemployment spells accelerate the depreciation of skills (Arrazola et al. (2005) and Hugonnier et al. (2019)). In the following subsections, we formalise the agents' problem.

[5]Agents cannot inherit debts. Lenders will charge a premium reflecting death risk when agents have debt.

[6]In this paper, we use the terms "university degree" and "college degree" interchangeably.

[7]Agents derive utility from bequeathing their wealth to the new comers, as in Cagetti and De Nardi (2006).

[8]$z_{u,NC}$ represents the lowest possible income, corresponding to being unemployed without a college degree (a detailed definition is provided further below).

[9]Students can borrow up to $\underline{a}$ to finance education but interest expenses could make student loan balances go beyond $\underline{a}$. We thus set an even lower limit $\underline{\underline{a}}$.

[10]College graduates are less likely to fall into unemployment and find employment at a faster rate.

[11]The approach is not different from Ben-Porath models, where skills can depreciate through time. See Ben-Porath (1967) and Manuelli et al. (2012).

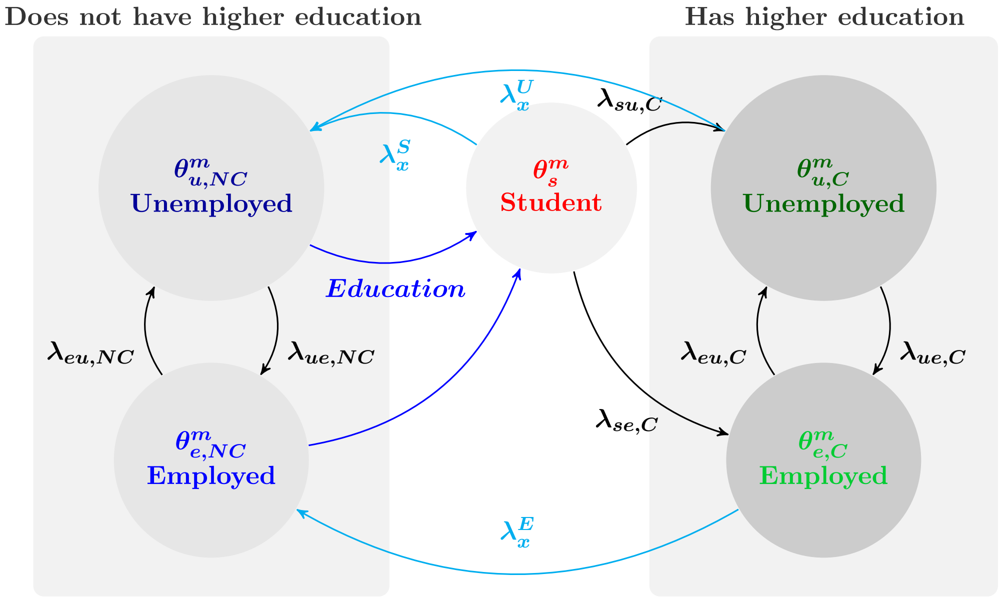

Fig. 3: Agent flows for a given educational ability level m

2.1.1 Unemployed ($\theta^m_{u,NC}$) and employed ($\theta^m_{e,NC}$) and no higher education

Non-graduate income is denoted by z_i, where i indicates the agent's employment status: u_{NC} (unemployed) and e_{NC} (employed). Income follows a two-point jump process, with $\lambda_{ue,NC}$ and $\lambda_{eu,NC}$ representing the Poisson rates of transitions from unemployment to employment and vice versa, respectively. Besides choosing consumption, the agent can also choose a time T where, if it has sufficient funds to cover the cost of education, it enrols in university and becomes a student. Agents face a mental cost when they become students, captured by the positive constant ε_0. Since the problem will be solved in the state domain, we will essentially be looking for a free boundary in b (or in b and a in the systems with student loans) that determines when the agent enrols in university. Let such boundaries in b and a be denoted by a $\dagger$ superscript and let b^* and a^* represent the target points where agents end up at after covering education costs. The general problem of a type $\theta^m_{u,NC}$ or $\theta^m_{e,NC}$ agent in any higher education regime is shown next. [12]

$$V_i(b,a,m) = \max_{T,\{c_s\}} E_t\left[\int_t^T e^{-(\rho+\kappa)(s-t)}[u(c_s)+\kappa q_s]\mathrm{d}s + e^{-(\rho+\kappa)(T-t)}(V_s(b^*,a^*,m)-\varepsilon_0)\right],$$

$$\begin{aligned}
& & & i = u_{NC}, e_{NC},\ \ m = H, L,\\
\text{s.t. } \mathrm{d}b &= \left(z_i + \left[r + \kappa_{\mathbb{1}\{b<0\}}\right]b - c - \phi_i(b,a)\right)\mathrm{d}t & & \text{and} \quad b \geq \underline{b} > -\infty,\\
\mathrm{d}a &= [r_A a + \phi_i(b,a) + \xi_i(b,a)]\mathrm{d}t - a\mathrm{d}q_j & & \text{and} \quad 0 \geq a \geq \underline{a} > -\infty,\\
\mathrm{d}z &= [z_{i+1} - z_i]\mathrm{d}q_{v_1} - [z_{i+1} - z_i]\mathrm{d}q_{\eta_1} & & z_{i+1} > z_i.
\end{aligned}$$

A type $\theta^m_{u,NC}$ agent receives unemployment benefits $z_{u,NC} = \mu w_{NC}$, where μ and w_{NC} are the replacement rate and non-graduate wage, respectively. Type $\theta^m_{e,NC}$ agents receive after tax income $z_{e,NC} = (1-\tau)w_{NC}$ and supply labour inelastically. The Poisson process q_ν (q_η) counts when an agent leaves unemployment (loses employment).[13] The Poisson process q_j counts when the student loan balance is cancelled (the arrival rate of this process is λ_{np}). If the agent has student loans, it pays them back according to $\phi_i(b,a)$ and may receive additional government

[12]For ease of exposition we omit the choice of early repayment of student loans at this stage. When we discuss students and college graduates further below we show how we introduce this feature.

[13]Arrival rates depend on employment and educational status. See Fig. 3 and further below.

support for its student loan balances with $\xi_i(b,a)$.[14] The functions $\phi_i(b,a)$ and $\xi_i(b,a)$ depend on the peculiarities of each higher education system and they will be described further below. Note that the drift of b has debt interest payments for b that include a death rate premium κ.[15] Following Moll (2016) we can show that the solution to this problem satisfies the Hamilton-Jacobi-Bellman (HJB) equation.[16]

$$(\rho+\kappa)V_i = \max_c u(c) + \kappa q + \frac{\partial V_i}{\partial b} S_{ib} + \frac{\partial V_i}{\partial a} S_{ia} + \lambda_{ij}\left[V_j - V_i\right] + \lambda_{np}\left[\tilde{V}_i - V_i\right], \tag{1}$$

where $\tilde{V}$ is the value function where the student loan balance is at zero and where the equation above satisfies the constraint

$$V_i(b,a,m) \geq V_s(b^*,a^*,m) - \varepsilon_0 \quad i = u_{NC}, e_{NC}, \tag{2}$$

in the region where higher education is not chosen. We can express the problem as a variational inequality (suppressing the dependence on m for ease of notation)

$$\begin{aligned} &\min\left\{\rho V_i - \ u(c) - \boldsymbol{A} V_i, V_i - V_s(b^*,a^*) + \varepsilon_0\right\} = 0, \\ \text{where} \quad &\boldsymbol{A} V_i = \kappa\left[q - V_i\right] + \frac{\partial V_i}{\partial b} S_{ib} + \frac{\partial V_i}{\partial a} S_{ia} + \lambda_{ij}\left[V_j - V_i\right] + \lambda_{np}\left[\tilde{V}_i - V_i\right]. \end{aligned} \tag{3}$$

When agents decide to go to university they will cover the cost of education as much as possible with student loans (if available), covering any remaining costs with b.[17] However, at any point in time thereafter agents are free to adjust their holdings of b and a, so as to pay their student loans early.[18] As mentioned previously, instead of looking for the optimal stopping time T, we will be solving for the threshold values $b_i^\dagger$ and $a_i^\dagger$ where the agent optimally chooses to invest in education. In systems such as TS and GT, we encounter single-asset problems. This means there is no dependence on a, and, as a consequence, the fourth and sixth terms on the right-hand side of equation (1) drop out. Additionally, there is no portfolio problem in the single asset case and as a consequence $V_s(b^*) = V_s(b^\dagger - (1-s)P)$. In the no-education region we have the standard first order condition in consumption given by

$$u'(c_i) = \frac{\partial V_i}{\partial b}. \tag{4}$$

Equation (3) is solved as a linear complementarity problem (LCP) - See Moll (2016) and Huang and Pang (1998).

2.1.2 Students (θ_s^m)

Students work a reduced number of hours and they supply labour inelastically. We scale their labour efficiency accordingly, $z_s = w_{NC} z_s$. After spending, on average, $\frac{1}{\Delta_{ed}}$ years as a student, the agent may graduate with (without) a job at rate $\lambda_{se,C}$ ($\lambda_{su,C}$). There is a risk that the agent will not graduate and become unemployed without a college degree, captured by λ_x^S. Note that $\lambda_{x,m}^S$ varies by innate educational ability m, but we suppress the subscript for ease of notation. Students do not pay income taxes. The HJB equation of students is

[14] This is a subsidy for student loan repayment, it is not a tuition subsidy.

[15] This is common for all agent types and covers the costs of unpaid debts due to death.

[16] For notational convenience we denote the drift of x, of an agent of type i, as S_{ix}. Also, we use notation that omits the dependence of V on b, a and m. We will make these explicit when strictly necessary.

[17] This akin to a so-called finance pecking order model. For further details, refer to Section 7.3 in the appendix.

[18] If we substitute $\hat{V} = \max\left\{V_s(b^*,a^*,m) - \varepsilon_0, V_i(b',a',m)\right\}$ in (2), where b' and a' are the values of b, a, after early repayment of student loans, and track when $V_s(b^*,a^*,m) > V_i(b',a',m)$, we can allow these agents to choose for early repayment of student loans as well.

$$(\rho+\kappa)V_s = \max_c \; u(c)+\kappa q+\frac{\partial V_s}{\partial b}S_{sb}+\frac{\partial V_s}{\partial a}S_{sa}+\lambda_{su,C}V_{u,C}+\lambda_{se,C}V_{e,C}+\lambda_x^S V_{u,NC}$$
$$-(\lambda_{su,C}+\lambda_{se,C}+\lambda_x^S)V_s+\lambda_{np}\left[\tilde{V}_s-V_s\right], \tag{5}$$

where the equation above satisfies the constraint (6)

$$V_s(b,a,m)\geq V_s(b',a',m), \tag{6}$$

in the region where early repayment of student loans is not chosen and where $b'=\max\{b+a,\underline{b}\}$ and $a'=a+b-b'$. We can express the problem as a variational inequality (suppressing the dependence on m for ease of notation)

$$\min\{\rho V_s - \; u(c)-\boldsymbol{A}V_s, V_s-V_s(b',a')\}=0, \tag{7}$$
$$\text{where} \quad \boldsymbol{A}V_s=\kappa\left[q-V_s\right]+\frac{\partial V_s}{\partial b}S_{sb}+\frac{\partial V_s}{\partial a}S_{sa}+\lambda_{su,C}V_{u,C}+\lambda_{se,C}V_{e,C}+\lambda_x^S V_{u,NC}$$
$$-(\lambda_{su,C}+\lambda_{se,C}+\lambda_x^S)V_s+\lambda_{np}\left[\tilde{V}_s-V_s\right].$$

The first order condition is analogous to that of (4).

2.1.3 Unemployed ($\theta^m_{u,C}$) and employed ($\theta^m_{e,C}$) with higher education

Agents with a college degree earn a college wage premium and thus earn higher labour income (that is $z_{e,C}=w_C(1-\tau)$ if employed and $z_{u,C}=\mu w_C$, if unemployed). Agents gain (lose) jobs at a higher (lower) rate, when compared to agents without a university education. The two HJB equations for those with a college degree are given by

$$(\rho+\kappa)V_i=\max_c \; u(c)+\kappa q+\frac{\partial V_i}{\partial b}S_{ib}+\frac{\partial V_i}{\partial a}S_{ia}+\lambda_{ij}\left[V_j-V_i\right]+\lambda_x^k\left[V_j-V_i\right]+\lambda_{np}\left[\tilde{V}_i-V_i\right], \tag{8}$$

where $i=u_C,e_C$, $j=u_{NC},e_{NC}$ and $k=E,U$. $\lambda_x^U>\lambda_x^E$ captures that skills gained by a college degree depreciate faster when the agent is unemployed. The equation above satisfies the constraint (9)

$$V_i(b,a,m)\geq V_i(b',a',m), \quad i=u_C,e_C. \tag{9}$$

We can express the problem as a variational inequality (suppressing the dependence on m for ease of notation)

$$\min\{\rho V_i - \; u(c)-\boldsymbol{A}V_i, V_i-V_i(b',a')\}=0, \tag{10}$$
$$\text{where} \quad \boldsymbol{A}V_i=\kappa\left[q-V_i\right]+\frac{\partial V_i}{\partial b}S_{ib}+\frac{\partial V_i}{\partial a}S_{ia}+\lambda_{ij}\left[V_j-V_i\right]+\lambda_x^k\left[V_j-V_i\right]+\lambda_{np}\left[\tilde{V}_i-V_i\right].$$

The first order condition is analogous to that of (4). The next subsection examines the specific features of each higher education system and details the student loan repayment function, $\phi_i(b,a)$, and student loan subsidies, $\xi_i(b,a)$

2.2 Higher education financing and agents' budget constraints

This paper evaluates five distinct higher education systems. The baseline regime, referred to as 'non-income-contingent loans (NICL)', represents a system with government-backed student loans and partial subsidies for the cost of education. NICL can be seen as a broad sketch of higher education financing in the United States. Only agents that can cover $P(1-s)$, the cost of a college degree after government subsidies, either with savings and/or student loans, are allowed to go to university. The next two systems make student loans income-contingent (ICL). Under these regimes, only those earning above a specified income threshold are required to repay their student loans, with any outstanding debt forgiven after 30 years. One ICL variant is closer to NICL (ICL1) while the other relies on the repayment scheme that is in place in England and Wales (ICL2). These two variants will shed light on how the design of loan repayments can affect outcomes. A fourth regime introduces a public subsidy that is funded by general taxation and is called 'TS'. Finally, a fifth system, labelled graduate taxes (GT), funds the cost of subsidies through a tax paid solely by employed graduates. We now provide a more detailed description of how each of these systems is modelled.

Tuition subsidies (TS) and graduate taxes (GT): The main defining feature of tuition subsidies and graduate taxes is that they are single asset models, i.e. there are no student loans. The cost of education that the agent faces is $P(1-s)$, where P and s are the price and subsidy rate from the state, respectively. When an agent in the TS and GT systems decides to go to university the agent subtracts $P(1-s)$ from its wealth stock and becomes a student. As shown below, the government funds tuition subsidies by adjusting the income tax rate.

Non-income-contingent student loans (NICL): Agents are now allowed to pay for higher education with student loans a (or combinations of b and a if the student loan debt limit is binding). The $\phi_i(b,a)$ function describes the student loan repayment scheme when an agent is of type i and has a wealth and student loan balance of b and a

$$\phi_i(b,a) = \begin{cases} -(r_A+\delta_A)a & \text{for } i = u_{NC}, e_{NC}, u_C, e_C, \\ 0 & \text{otherwise.} \end{cases} \tag{11}$$

As a result, the student loan balance evolves according to

$$\mathrm{d}a = \begin{cases} -\delta_A a \mathrm{d}t & \text{for } i = u_{NC}, e_{NC}, u_C, e_C, \\ r_A a \mathrm{d}t & \text{otherwise.} \end{cases} \tag{12}$$

If the agent holds student loans, it pays $(r_A+\delta_A)a$, the interest and amortisation rates on student debt, regardless of its income state. The exception is for students, who accrue debt while at university. Debt forgiveness is not allowed, so the debt cancellation premium $\lambda_{np} = 0$ and $r_A = r + \kappa$.[19] $\xi_i(b,a)$ is set to zero for all agent types. This follows closely federal unsubsidised student loans in the U.S.

Income-contingent loan with generous repayment subsidies (ICL1): ICL1 builds on NICL and it introduces additional income-contingent protections. The student loan repayment scheme is given by

$$\phi_i(b,a) = \begin{cases} -(r_A+\delta_A)a & \text{for } i = e_C, \\ 0 & \text{otherwise,} \end{cases} \tag{13}$$

[19] As NICL mimics the U.S. student loan system, the interest rate on student loans is equal to the sum of the risk free rate plus a spread equal to κ. This is discussed further below in the calibration section.

and subsidies to student loan payments are described by

$$\xi_i(b,a) = \begin{cases} 0 & \text{for } i = e_C, \\ -(r_A + \delta_A)a & \text{otherwise.} \end{cases} \tag{14}$$

Therefore, the student loan balance evolves according to

$$\mathrm{d}a = -\delta_A a \mathrm{d}t - a\mathrm{d}q_j \quad \text{for all } i. \tag{15}$$

Agents repay student loans only upon reaching a sufficiently high income (when they attain type $\theta^m_{e,C}$, i.e. they become employed graduates). The government covers interest and amortisation payments on student loans otherwise. Furthermore, agents are eligible for debt forgiveness, with loans being cancelled, on average, after $1/\lambda_{np}$ years. The Poisson process q_j counts when an agent's student loan balance is cancelled. The government recovers loses due to death by charging a premium on student loans and thus $r_A = r + \kappa$. Losses arising from debt cancellation are financed through revenue generated by labour income taxes.

Income-contingent loans with repayment subsidies (ICL2): ICL2 builds upon NICL but introduces income-contingent protections that differ from those in ICL1. Agents are allowed to receive debt forgiveness on the same terms as ICL1. Agents pay their student loans only when they have earnings (the sum of labour and capital income) above the threshold z_T. Any earnings above that threshold are taxed at a rate r_p and this tax contributes towards reducing the student loan balance.[20] Note that even an unemployed agent without a college degree carrying student loans (say because it suffered a college dropout or skill depreciation shock) that is wealthy in b can still be liable for student loan repayments. Employed graduates are charged an interest rate r_A on their student debt. Students accumulate debt at a rate of r_A and do not make payments. This system follows closely that of England and Wales.[21] The student loan repayment scheme is given by

$$\phi_i(b,a) = \begin{cases} r_p \mathbb{1}_{\{a<0\}} \max\{z_i + r\max\{b,0\} - z_T, 0\} & \text{for } i = u_{NC}, e_{NC}, u_C, \\ 0 & \text{for } i = s, e_C, \end{cases} \tag{16}$$

and subsidies to student loan payments are described by

$$\xi_i(b,a) = \begin{cases} -r_A a & \text{for } i = u_{NC}, e_{NC}, u_C, \\ 0 & \text{for } i = s, e_C. \end{cases} \tag{17}$$

As a result, the student loan balance evolves according to

$$\mathrm{d}a = \begin{cases} [r_p \mathbb{1}_{\{a<0\}} \max\{z_i + r\max\{b,0\} - z_T, 0\}]\mathrm{d}t - a\mathrm{d}q_j & \text{for } i = u_{NC}, e_{NC}, u_C, \\ r_A a\mathrm{d}t - a\mathrm{d}q_j & \text{for } i = s, \\ [r_A a + r_p \mathbb{1}_{\{a<0\}} \max\{z_i + r\max\{b,0\} - z_T, 0\}]\mathrm{d}t - a\mathrm{d}q_j & \text{for } i = e_C. \end{cases} \tag{18}$$

ICL2 differs from ICL1 in two aspects. First, ICL1 charges student loan payments depending on the labour income state whereas ICL2 does according to earnings. Second, in ICL2 the government does not provide student debt amortasiation subsidies for those receiving income-contingent protections. In ICL1, the student loan balance decreases continuously, irrespective of

[20] If these payments do not offset interest, the student loan balance will keep growing.

[21] In England and Wales student loan interest rates are charged during studies and vary depending on income later in life. The rate charged to students and high income earners tends to be larger than what would be considered a proxy for the risk free rate.

the individual's income state. In contrast, under ICL2, the balance may increase if tax payments on earnings above the threshold z_T are insufficient to cover the accruing interest.

In NICL and ICL2 there is one additional subsidy from the state in the student loan program. Any agent with a negative drift at $\underline{\underline{a}}$, will have interest payments on student debt covered by the government. This is done to prevent mass escaping the state space.[22] These costs are covered through tax revenue raised from labour income. In the next subsection we describe how agents interact with the other sectors of the economy.

2.3 Firms, government, education and asset market

The rest of the model consists of a representative firm, an asset market, and the government. Fig. 4 illustrates the interactions between the various economic agents. The production sector follows the framework outlined in Nuño and Moll (2018), where a representative firm hires labour and rents capital to produce output. The labour input is modelled using a CES aggregator of college-educated and non-college-educated workers, with the distribution of worker types determined endogenously. Agents supply labour to the representative firm and, in return, receive wages net of taxes. Agents also supply capital to the representative firm via a financial market, which is excluded from the figure as it functions as an invisible intermediary. In return, agents earn interest income. Agents' expenditures consist of consumption goods and education-related costs. The government operates under a balanced budget, funding both the unemployment insurance programme and the higher education system mprimarily with labour income taxes.[23]

Higher education entails a fixed resource cost, calibrated as a share of GDP per capita to ensure comparability across different higher education systems with the same relative tuition costs. This is a deliberate modelling choice, designed to evaluate the impact of P on the capital market imperfections in educational investments and, consequently, on the rankings of the various higher education regimes. The significance of P warrants particular attention, especially given the dramatic rise in tuition costs in the United States and Europe (see Fig. 29, Fig. 30 Fig. 31 in the appendix).

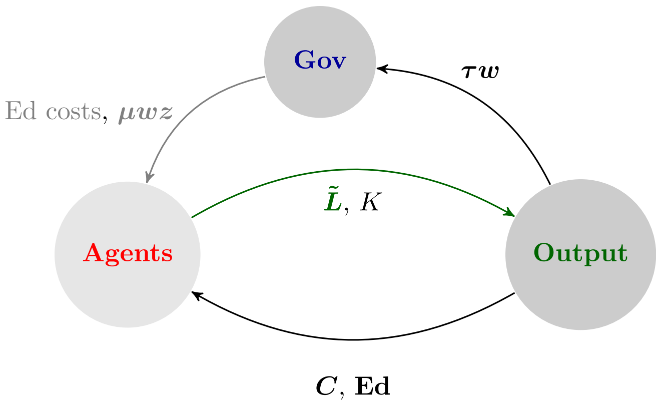

Fig. 4: Common flows in all HE systems

[22]The small amount of mass of agents that reach the lower bound on a (denoted as $\underline{\underline{a}}$) does not affects results for the calibrations considered in this paper.

[23]In systems with student debt, losses due to death are financed by a premium on student loans reflecting mortality risk.

2.3.1 Representative firm

There is a representative firm with Cobb-Douglas technology. The firm rents capital from agents, which depreciates at a rate δ, and hires labour. The production function is given by

$$Y = AK^{\alpha}\tilde{L}^{1-\alpha}, \tag{19}$$

where A is a positive constant and α is the capital share. The effective labour supply $\tilde{L}$ is given by a CES aggregator of the labour supply of workers with and without a college degree as well as that of students

$$\tilde{L} = \left(\chi[\theta_{e,NC} + z_s\theta_s]^{\nu} + (1-\chi)\theta_{e,C}^{\nu}\right)^{\frac{1}{\nu}}, \tag{20}$$

where students' effective labour supply is scaled by z_s to capture their working hours.[24] Factor prices are given by the next three expressions:

$$r = \alpha\frac{Y}{K} - \delta, \tag{21}$$

$$w_{NC} = (1-\alpha)\frac{Y}{\tilde{L}^{\nu}}\chi[\theta_{e,NC} + z_s\theta_s]^{\nu-1}, \tag{22}$$

$$w_C = (1-\alpha)\frac{Y}{\tilde{L}^{\nu}}(1-\chi)\theta_{e,C}^{\nu-1}. \tag{23}$$

Equation (21) gives us capital demand.

2.3.2 Labour income taxes

The government has a balanced budget constraint and raises revenue from labour income with a flat tax applied to workers, τ, to finance the unemployment insurance programme and public expenditure in education. Hence, the income tax rate τ is

$$\tau = \frac{\overbrace{\mu[w_{NC}\theta_{u,NC} + w_C\theta_{u,C}]}^{\tau_{UI}}}{w_{NC}\theta_{e,NC} + w_C\theta_{e,C}} + \frac{\text{Public Ed spending}}{w_{NC}\theta_{e,NC} + w_C\theta_{e,C}}. \tag{24}$$

The first term, τ_{UI}, is the tax rate needed to cover unemployment benefits. The second term comprises the net expenditures incurred to finance the HE system.[25] The unemployment benefit system is common in all the five regimes being considered. In GT we have two income tax rates

$$\tau_{NC}^{GT} = \frac{\mu[w_{NC}\theta_{u,NC} + w_C\theta_{u,C}]}{w_{NC}\theta_{e,NC} + w_C\theta_{e,C}}, \tag{25}$$

$$\tau_{C}^{GT} = \frac{\mu[w_{NC}\theta_{u,NC} + w_C\theta_{u,C}]}{w_{NC}\theta_{e,NC} + w_C\theta_{e,C}} + \frac{\text{Public Ed spending}}{w_C\theta_{e,C}}. \tag{26}$$

The first tax rate, τ_{NC}^{GT}, applies to non-graduates, who do not contribute to public education expenditure. In contrast, graduates pay τ_C^{GT}, provided they are not affected by skills depreciation shocks. Public education spending is calculated as $P(1-s)$ times the flow of agents entering higher education, plus the weighted sum of interest rate subsidies ξ_i. In ICLs, public education

[24] Note that $\theta_i = \sum_{m=1}\theta_i^m$.

[25] Note that in NICL and ICLs the government incurs expenses to run the student loan program but that it also receives interest income from student loan repayments. So the second component of the tax rate is net expenditure in higher education.

spending also covers student debt cancellations $\lambda_{np}A$, where A is the aggregate student loan balance.[26] Note that $\xi_i = 0$ in systems without student loans.

2.3.3 Student loan interest rates and asset market

Agents pay their student loan balances according to the debt repayment schemes mentioned earlier. In all student loan programs, the government charges a premium on loans so as to cover unpaid balances due to death

$$r_A = r + \kappa. \tag{27}$$

In systems with student loans, the government acts as an intermediary, raising funds in the financial market, issuing student loans to agents and acting as guarantor of debt payments. In the next subsection we define what is an equilibrium in the economy and how we rank welfare.

2.4 General equilibrium

The stationary equilibrium in this model is defined by a set of policy functions in consumption and educational investment (given by the HJB equations shown above) for each agent type, a joint income and wealth distribution that is ergodic, a government balanced budget and a risk free rate that clears the asset market. During transitions, the asset market clears at every instant. The income and wealth distribution is governed by the Kolmogorov Forward Equations (KFE) and the density is represented by g.[27] Market clearing requires $K_S - K_D = 0$, where capital supply is defined as

$$K_S = \sum_m \sum_i \int_{\underline{a}}^0 \int_{\underline{b}}^\infty (b + a) g(b, a, i, m) \mathrm{d}b \mathrm{d}a,$$

where we sum over m ability levels and i agent types. Capital demand being equal to capital supply implies the national accounting identity $Y = C + I + G +$ Education costs.[28] There is no proof of existence and uniqueness of equilibrium for the model with educational choice. The downward sloping and continuous demand of capital remains the same as in Aiyagari (1994). Nevertheless, capital supply is affected by the different education types (Angelopoulos et al. (2017)). Quantitative evaluations for a large parameter space show that it is the case that the aggregate capital supply K_S is monotonically upward sloping, approaching ρ from below, continuous and that there is a single crossing of capital demand and supply. We evaluate aggregate and individual welfare via the consumption equivalent gain (CEG), denoted as

$$\tilde{c} = \left[\left(\frac{V_c}{V_o} \right)^{\frac{1}{1-\sigma}} - 1 \right] * 100. \tag{28}$$

where V_0 and V_c denote the steady state aggregate value in the baseline (NICL) and alternative regimes, respectively. Note that the CEG will be expressed in percentage terms. For the calculation of aggregate CEG, V_c and V_o are determined as follows:

$$\sum_m \sum_i \int_{\underline{a}}^0 \int_{\underline{b}}^\infty V(b, a, i, m) g(b, a, i, m) \mathrm{d}b \mathrm{d}a. \tag{29}$$

[26] As mentioned above, if any agent has a negative drift in a at $\underline{a}$, the government steps in to cover interest payments so as to prevent mass escaping the state space. This is also part of public expenditure in education.

[27] The KFEs are shown in the appendix.

[28] A heuristic proof is left in the appendix.

The CEG will be calculated as an average for the entire economy (as shown in (29) above) and also for specific income, wealth, and educational ability groups. In some cases, the CEG will be examined at each point in the state space (using $V(b,a,i,m)$), providing a disaggregated perspective on which parts of the state space support or oppose moving away from NICL. Since each regime results in a different distribution of income and wealth, the disaggregated CEG comparisons will be unweighted comparisons of raw value functions. Accordingly, the aggregate welfare analysis will be complemented by an evaluation of the gains and losses experienced by different groups under higher education reforms, as well as a comparison of the income and wealth distributions across higher education systems.

Positive values of $\tilde{c}$ indicate that agents in the NICL system would need their lifetime consumption increased by $\tilde{c}$ per cent to be as well off as they would be in the alternative system. Conversely, negative values of $\tilde{c}$ imply that lifetime consumption in the NICL system would need to be reduced by $\tilde{c}$ per cent to make agents as worse off as in the alternative higher education system. The model is solved numerically using the finite differences method outlined in Achdou et al. (2022), on non-uniform grids. The agent's decision to become a student and the decision to make early repayments of student loans are computed using an LCP solver, as described in Moll (2016).

2.5 Calibration

The baseline calibration of the model is shown in Table 1. The calibration is annual. The model economy has 36 parameters. These are discussed below in separate categories. The benchmark higher education financing regime is NICL, and we choose parameters by matching selected U.S. data moments and calibrating the rest based on studies focused in the U.S. The baseline economy hits all of its target moments except for wealth inequality.[29] The model does well with untargeted moments as well although it generates slightly more debt than in the data and a smaller ratio of the mean to median student debt.[30]

Preferences: Preferences are described by a constant relative risk aversion utility function with risk aversion coefficient σ, set to the standard value of 2, a subjective discount rate ρ, a bequest taste $\hat{\phi}$, the parameter governing the strength of the mental cost of becoming a student ε_0 and the death rate κ. The subjective discount rate is set by matching the capital-output ratio, estimated from 2018 NIPA tables to be at 3.04.[31] The bequest taste parameter is set by approaching as much as possible a Gini coefficient of wealth of 0.801, following Davies et al. (2011). The mental cost parameter ε_0 is set so as to match the fraction of the population with a college degree. According to the National Center of Education Statistics (NCES) the share of college graduates stood at 35% in 2018. The death rate κ is set to 0.0204, implying an average work span of 49 years.[32] The intergenerational transmission of educational ability is taken from Abbott et al. (2019) and we elaborate further on its implementation in the appendix.

Labour market transitions: The labour market transition rates from unemployment to employment, and vice-versa, are taken from Lise et al. (2016).[33] One can see in Table 1 how labour

[29] This is unsurprising as the model lacks some of the usual modeling approaches (in the interest of parsimony) to generate more wealth inequality. See De Nardi and Fella (2017).

[30] In Section 7.8 in the appendix, we compare the model's distribution of the age of enrolment to the data. As discussed in Section 3, this helps assess how the perpetual youth framework may bias results relative to a life-cycle approach.

[31] The estimate is produced by dividing the current cost net stock of fixed assets by nominal GDP, yielding a similar result to those found in the literature. For instance see Boppart and Krusell (2020).

[32] This approximates working from 18 years of age until retirement at 67, following the Social Security Administration's guidelines for those born after 1959.

[33] Remark that the transition rates in Lise et al. (2016) are estimated for U.S. white males only, so they represent relatively better labour market outcomes. To keep the model tractable these rates are treated as exogenous. We

market outcomes are more favourable for graduates as they face a higher probability of being employed and lower probability of falling into unemployment. The transition rates from student to educated is set to $\Delta_{ed} = 0.25$, reflecting that on average it takes four years to complete a bachelor's degree in the U.S.[34] The flow from student to educated Δ_{ed} is split into transitions to unemployed and educated ($\lambda_{su,C}$), and employed and educated ($\lambda_{se,C}$). According to the NCES, roughly two thirds of students find employment within the first 9 months after graduation - Staklis and Bentz (2016). This figure is roughly constant despite fluctuations over the business cycle. The skills depreciation rate is taken from Manuelli et al. (2012). The magnitude seems to be more or less the same among other papers using Ben-Porath type models, for instance Ionescu (2009). The doubling of this rate for those that are unemployed reflects evidence highlighted in Arrazola et al. (2005) and Hugonnier et al. (2019). The replacement rate μ is taken from estimates of the U.S. Department of Labor.

Education, ability and college wage premium: The total cost of education, relative to GDP per capita, rescaled to only take into account workers, and based on a four year education is equal to 1.28. Scaling educational expenses relative to GDP per capita allows better comparison between different HE systems that may have different steady state output. We elaborate on how we compute P when we discuss equation (43) in the appendix. Section 7.6.1 in the appendix has a sensitivity analysis with larger/smaller costs of education. The χ share in the labour CES aggregator is set so as to match a college wage premium, $\psi = w_C/w_{NC}$, of 1.7 in the baseline NICL, following evidence from James (2012) and Valletta (2018).[35] The baseline subsidy rate is set to 0.47, following Athreya et al. (2019). The college dropout rates by educational ability $\lambda^S_{x,1}$ and $\lambda^S_{x,2}$ are taken from Light and Strayer (2000), where we convert in annual rates the probability of not graduating from university and where we combine the two bottom and top AFQT score quartiles into low and high educational ability. We set z_s to 0.50625, based on U.S. working students average hours worked - Carnevale et al. (2015) and Sonnet (2010).

Student loans and debt limits: The amortisation rate in NICL and ICL1 is set to 1/15. This corresponds to half the length of the maximum maturity in the *Standard Repayment* schedule for student loans in the United States. The reason we use this rate is twofold. First, we attempt to strike a balance between keeping a large state space range where consumption can remain positive when indebted (which requires a lower amortisation rate). Second, the repayment length should reflect what we see in the data, yielding someting broadly in line with the repayment time for the median borrower reported in Looney and Yannelis (2019).[36] The rate r_A in NICL is taken from the Direct undergaduate student loan interest rate set by the Treasury Department in the academic year 2018-2019.[37] Using the re-scaled GDP per capita method outlined in the appendix, we obtain the values for $\underline{b}$ and $\underline{a}$. In the former we take the value of mean credit limit \$20571, estimated from the 2019 SCF, following Athreya et al. (2019), where after converting

thus miss how they could change in response to shifts in the educational composition of the labour force. However, capturing this endogeneity would require a more complex framework.

[34]According to NCES, in the U.S., the most common is to graduate in 4 years. Results with further sensitivity analysis on Δ_{ed} can be reproduced upon request.

[35]In a previous version of this paper we imposed a fixed college wage premium on all HE regimes as the last decades have seen a stable, if not rising, college wage premium in both the US and UK despite large increases in the supply of college educated workers. In this paper we let the college wage premium respond to market forces as we change the HE financing policy. Belfield et al. (2018a) and Belfield et al. (2018b) have shown that the premium is driven by substantial heterogeneity. Introducing heterogeneity in ψ is left for an extension.

[36]Looney and Yannelis (2019) report that the median borrower who took up to \$50,000 in 2014 dollars took about eleven years to repay student debt in 2000-2014, with an increasing length of repayment for the most recent cohorts.

[37]The U.S. student loan program charges interest rates that are well above the government's borrowing rate, and by some accounts, has yielded net income to the government in some years. Since the spread in 2018-2019 was at 2.05 % and is almost equivalent to the death rate, we set the spread equal to κ.

Table 1

	Values	Description	Source
σ	2	CRRA	Nuño and Moll (2018)
$\lambda_{ue,NC}$	1.884	Transition rate $z_{u,NC} \to z_{e,NC}$	Lise et al. (2016)
$\lambda_{eu,NC}$	0.132	Transition rate $z_{e,NC} \to z_{u,NC}$	Lise et al. (2016)
$\lambda_{ue,C}$	1.608	Transition rate $z_{u,C} \to z_{e,C}$	Lise et al. (2016)
$\lambda_{eu,C}$	0.072	Transition rate $z_{e,C} \to z_{u,C}$	Lise et al. (2016)
$\lambda_{su,C}$	$\Delta_{ed}\frac{1}{3}$	Transition rate $z_s \to z_{u,C}$	Staklis and Bentz (2016)
$\lambda_{se,C}$	$\Delta_{ed}\frac{2}{3}$	Transition rate $z_s \to z_{e,C}$	Staklis and Bentz (2016)
λ_x^E	0.024	Employed obsolescence rate	Manuelli et al. (2012)
λ_x^U	0.048	Unemployed obsolescence	Manuelli et al. (2012) and Arrazola et al. (2005)
$\lambda_{x,1}^S$	0.1940	Dropout rate high ability	Light and Strayer (2000)
$\lambda_{x,2}^S$	0.3064	Dropout rate low ability	Light and Strayer (2000)
s	0.47	Subsidy rate	Athreya et al. (2019)
μ	0.382	Replacement rate	U.S. Department of Labor (2019)
Δ_{ed}	0.25	Inverse years until grad	4 year degree
A	1	Productivity	Normalisation
$\underline{b}$	-0.1872	Exogenous b limit	SCF (2019) & Athreya et al. (2019)
$\underline{a}$	-0.5232	Exogenous a limit	U.S. Department of Education (2019)
$\underline{\underline{a}}$	-1.0111	Lower bound on a	2.18*$\underline{a}$
P	1.28	Education cost †	College Board (2018)
α	0.36	Capital income share	Nuño and Moll (2018)
ν	0.6	CES production	Card and Lemieux (2001)
δ_A	1/15	Amortisation in NICL & ICL1	Looney and Yannelis (2019)
κ	1/49	Worker death rate	S.S.A.⋄ (2018)
λ_{ij}^a	‡	Intergenerational ability trans	Abbott et al. (2019)
z_s	0.50625	Student work hours	Carnevale et al. (2015)

Exogenously calibrated parameters. † Average cost of going to university. ⋄ Social Security Administration. ‡ The intergenerational transition matrix of ability is shown in the appendix.

Table 2

	Values	Description	Source
λ_{np}	1/30	Premium on student loans	ICL1 and ICL2
r_p	0.09	ICL2 graduate tax	England and Wales (2018)
z_T	0.3246	ICL2 income threshold	England and Wales (2018)

Parameters exclusive to ICL1 and ICL2.

Table 3

Parameter	Value	Description	Targeted moments	Model	Data	Source
ρ	0.028	Discount rate	K/Y	3.04	3.04	NIPA (2018)
χ	0.423	CES income share	ψ	1.7	1.7	Valletta (2018)
$\hat{\phi}$	0.618	Altruism strength	Wealth Gini	0.649	0.801	Davies et al. (2011)
ε_0	1.249	Mental cost edu	Graduate share	35%	35%	NCES (2018)
δ	0.088	Depreciation K	$r_A - r$ spread	2.05%	2.05%	USDE (2018)
			Untargeted moments			
			Mean/Median debt†	1.061	1.329	NCES (2018)
			Mean/Median earnings ‡	1.299	1.374	U.S. Census Bureau (2018)
			Mean/Median wealth	4.868	6.132	SCF (2019)
			Student loan/GDP	8.20%	7.64%	Federal Reserve (2018)
			Share with debt*	14.18%	20.82%	Federal Reserve (2018)
			Share net debtors ⋄	9.31%	10.43%	SCF (2019)

Endogenously calibrated parameters and targeted and untargeted moments. The symbols *, ⋄, denote the share of working age people holding student debt and the share with negative wealth, respectively. † Student debt. ‡ Based on re-scaled mean income (see the appendix).

to 2018 dollars we obtain a debt limit $\underline{b}$ equal to -0.1872.[38] As for the latter, we set the student debt limit (4 year degree cumulative) $\underline{a}$ to -0.5232. This reflects the total aggregate loan limit for independent undergraduate students of $57500 in 2018, converted following the methodology outlined in the appendix. Although agents can borrow up to $\underline{a}$ to go university, interest may push them over this limit. We thus extend the student debt dimension up to $\underline{\underline{a}}$, a parameter that we choose so as to allow the loosest possible limit and such that consumption is always positive for all the experiments considered herein. The result is a value of $\underline{\underline{a}} = 1.9325\underline{a}$.

ICL2 parameters: The graduate tax in ICL2 is described by two parameters: z_T and r_p. The threshold z_T is set to mimic England and Wales' student loan system, matching the ratio of the student loan taxable threshold to GDP per capita (rescaled to only account for workers) while the tax rate r_p on earnings above the threshold is set to 9 %. Following the methodology in the calibration for P, we translate z_T to a comparable figure for the US, and we thus set $z_T = 0.3246$. We leave the details of the computation in the appendix.

Production: Three parameters describe the productive technology in the economy. These are the capital elasticity α, total factor productivity A and depreciation δ. The first two are set to commonly used values, 0.36 and normalised to 1, respectively - Nuño and Moll (2018). The depreciation rate adjusts so that we can generate an equilibrium interest rate that produces a student loan spread equal to κ while respecting market clearing and the capital output ratio target. This yields a value of 0.0883, close to that in Nuño and Moll (2018). The elasticity of substitution between labour types is set to 2.5, following Card and Lemieux (2001), which implies $\nu = 0.6$.

3 Steady state results

Table 4 and Fig. 5 present aggregate welfare gains alongside other key indicators for each system.[39] Welfare gains are measured relative to the benchmark regime, NICL. Focusing on Fig. 5, we see two striking results. First, while income-contingent loan systems offer significant welfare gains, these can vary substantially depending on how its design. ICL1, a more generous scheme, results in greater welfare improvements. Second, full or even partial tuition subsidies, yield the largest CEG vis-à-vis NICL. Table 4 shows that welfare rankings move in the same direction with the share of college graduates, lower inequality and lower net debtor shares. Notably, systems with larger welfare gains tend to have higher equilibrium interest rates *with the lowest shares of the population in net debt*. This result aligns with the insights of Obiols-Homs (2011), who links the distribution of debtors to welfare outcomes.[40] In addition, the findings suggest that higher income tax rates have a minimal role in predicting welfare losses.

There are four main reasons behind the relative success of TS and GT. First, we have a model environment where earnings are higher and unemployment spells are shorter in the graduate labour market. Not only is this of benefit to the individual but it also has indirect general equilibrium benefits such as a lower cost for the unemployment insurance scheme (although overall tax rates might increase due to education expenditures). Systems that place a larger mass of agents in this labour market will, therefore, tend to achieve higher welfare. Second, the protections against bad outcomes provide more incentives for educational investments. Income

[38]Aggregate welfare is sensitive to debt limits, as pointed out by Obiols-Homs (2011). Therefore, a sensitivity analysis on debt limits is carried out to illustrate how they affect the rankings of the higher education funding schemes discussed herein.

[39]In Table 4, the TS and GT system columns have a percentage attached to denote the fraction of education costs that are covered by the state.

[40]The results also underscores those of Dávila et al. (2012) and Nuño and Moll (2018), who discuss how agents' savings behaviours can create pecuniary externalities that lead to a suboptimal capital stock and depressed wages.

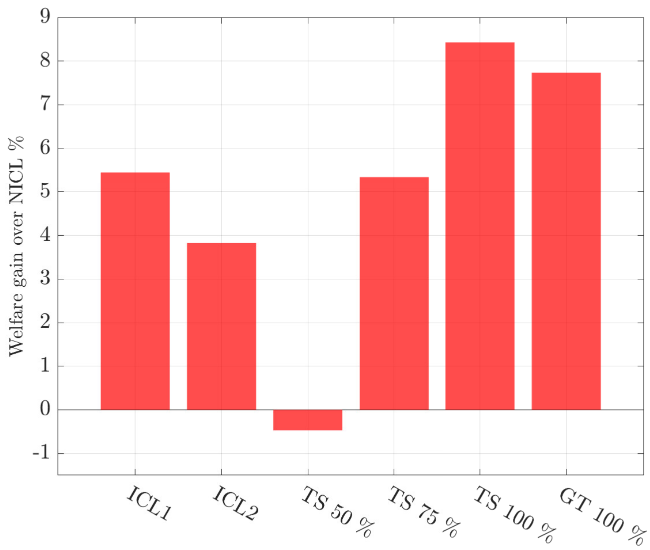

Fig. 5: Consumption equivalent gain of income contingent student loans 1 and 2 (ICL1 and ICL2), tuition subsidies (TS) and graduate taxes (GT) subsidised at 50, 75 and 100 % of educational costs, relative to the baseline (non-income-contingent student loans - NICL).

contingent student loans do much better than the benchmark system in this regard, especially as protections against bad outcomes increase. This is clear in ICL1's superior performance over ICL2. Despite having the same debt limit and debt cancellation policies, ICL1 is more generous in its protections for bad outcomes. TS and GT go even further in that agents do not incur as much debt, or any at all, to become students. Third, although student loans deliver substantial gains, they have debt limits. In an environment where there is college dropout and retraining risk (due to skill depreciation shocks) some agents may be stuck waiting to either pay student debt or have enough savings to join again the graduate labour market. In this regard TS and GT do better, as there is no limit in the number of times one becomes a student. Fourth, since TS and GT systems generate less debtors the economy is less susceptible to the price effects of debt. The wealth distribution shifts to the right, reducing the population share of net debtors. As TS and GT systems are less risky, precautionary savings drop and wealth inequality falls. In addition, the effective labour supply rises, pushing up the equilibrium interest rate. So we end up with systems that generate relatively more lenders with higher asset income and less inequality. We elaborate on this fourth point further below in Section 3.1.

Table 4

	NICL	ICL1	ICL2	TS 50 %	TS 75 %	TS 100 %	GT 100 %
K	2.439	2.454	2.432	2.442	2.478	2.462	2.385
$\tilde{L}$	0.429	0.446	0.441	0.429	0.447	0.458	0.442
r	3.009	3.257	3.242	2.987	3.200	3.444	3.408
Graduates %	35.000	43.060	40.351	34.751	43.620	52.745	40.773
τ %	6.194	11.022	10.379	6.460	9.951	14.908	19.660*
τ_{UI} %	2.465	2.286	2.337	2.479	2.279	2.148	2.317
Gini$_{b+a}$	0.649	0.532	0.602	0.637	0.510	0.352	0.380
Net debtors % $b+a$	9.307	9.500	17.029	4.673	3.080	1.515	1.317
Net debtors % b	4.129	2.634	3.293	4.673	3.080	1.515	1.317
CWP	1.700	1.476	1.547	1.707	1.462	1.250	1.536
High ability %	47.971	49.859	49.422	48.079	49.564	51.256	49.178

Steady state general equilibrium results. In GT we have two tax rates; * is τ_H^{GT} and τ_{UI} is τ_L^{GT}.

Systems with more net debtors and greater inequality result in lower aggregate CEG. If a relatively high net debtor share is compounded with a larger interest rate, welfare will be depressed even further. As we can see in Table 4, systems with student loans are more prone to

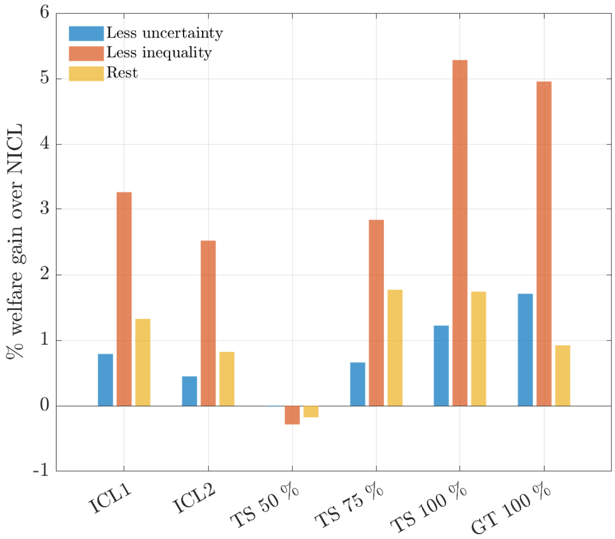

Fig. 6: Floden (2001) decomposition of consumption equivalent gain of income contingent student loans 1 and 2 (ICL1 and ICL2), tuition subsidies (TS) and graduate taxes (GT) subsidised at 50, 75 and 100 % of educational costs, relative to the baseline (non-income contingent student loans - NICL).

the negative impact on welfare coming through the price effect described in Obiols-Homs (2011). Whilst income contingent loan systems can be tailored to shield agents from the effect of interest rates, they may also be designed in a way, such as in ICL2, where debt balances accumulate during non payment spells, effectively prolonging the repayment period.[41] Remark that in NICL and ICL2, agents accrue debt when they don't have a high enough income.[42] Furthermore, even if the amount of debt is notional and may not affect those on very low incomes, the government still has to raise revenue to cover interest payments and cancellations. In equilibrium, ICL2 ends up being fiscally more expensive than TS 75% and close to that of ICL1's fiscal price tag, despite being less generous and delivering lower gains.

Changing higher education funding alters the distribution of income, education, and wealth, as well as the composition of the labour market, thereby transforming the uncertainty agents face. A decomposition of aggregate welfare gains, following Floden (2001), is shown in Fig. 6. The decomposition reveals that most of the welfare improvements from moving away from NICL arise due to reductions in inequality across the alternative funding systems. Furthermore, it illustrates that the benefits of reduced inequality and uncertainty grow as the funding system becomes more generous. As wealth inequality is intricately linked with the make up of debtors/lenders, it is natural that results in Table 4, Fig. 5 and Fig. 6 point to higher welfare in systems that generate less debtors and less inequality.[43]

Although aggregate welfare gains relative to NICL are positive for all systems (except TS 50%), averages obscure the distribution of gains and losses and whether most agents support changing higher education financing. Fig. 7 reveals that most alternatives deliver non-negative

[41]See Waltmann (2022) for a recent analysis of the distributional impact of tweaking repayment thresholds and student loan interest rates in England and Wales.

[42]This is one of the main distinctions between ICL1 and ICL2. In the former the government covers student loan repayments when agents do not make contributions whereas in the latter debt may continue to accrue. Changing z_T and r_p can accentuate or soften these effects.

[43]The welfare gains reported in Fig. 5 are likely conservative. In a perpetual youth setting, agents are more inclined to save and eventually enrol in university. In contrast, in a life-cycle environment, factors such as increasing mortality risk, declining educational ability, and rising opportunity costs reduce the feasibility of deferring education to save for university, which should result in fewer graduates under a similar calibration. Consequently, higher education systems that facilitate earlier enrolment for individuals who might otherwise forgo education are likely to generate greater welfare gains within a life-cycle framework.

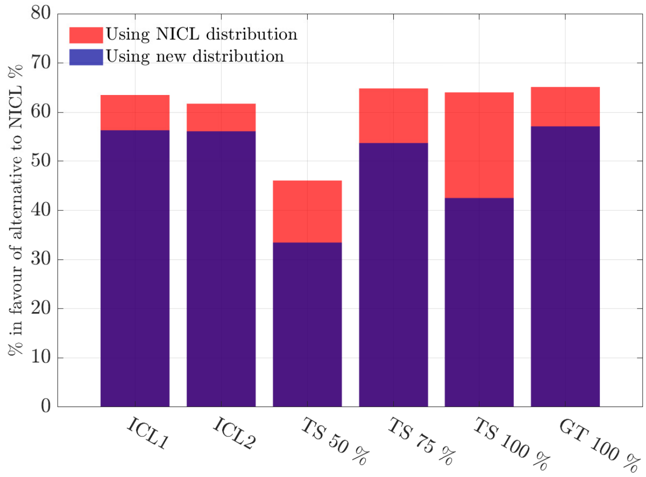

Fig. 7: Total share of the population in favour of moving away from NICL. The 'new' distribution is that of the alternative regime (ICL1, ICL2, TS, GT, respectively).

welfare gains to more than half of the agents, whether the pre- or post-reform distribution of agents is used. The biggest discrepancy between distributions is in the case of TS 100%, which also delivers the largest aggregate steady state welfare gains. Two forces are at play in this seemingly contradictory result. First, the vast majority of gains are concentrated in low wealth agents and the gains in these groups are large enough to compensate for losses of high wealth agents. Second, the results depend on the distribution that we use to weigh population shares when we ask which fraction of agents is in favour of the policy change. The distribution in NICL places more mass in low wealth (especially net debtors) groups whereas more generous public financing systems have distributions with relatively less debtors. This suggests the necessity of a disaggregated analysis of welfare gains.[44] Before doing so, we repeat the exercise above with many combinations of debt limits $\underline{b}$ and $\underline{a}$, subsidy rates and various values of P in order to evaluate further the price and quantity effects outlined in Obiols-Homs (2011).[45]

3.1 Borrowing limits and welfare

We have seen that aggregate welfare gains appear to move in lockstep with net debtor shares and inequality. In this section we show how much aggregate CEG results change as we vary debt limits $\underline{b}$ and higher education funding policy ($\underline{a}$ and s). In a first round of experiments, we keep the NICL benchmark at the baseline calibration and compute steady state results for all other higher education financing schemes. We then repeat this exercise by also changing the cost of education P.

The patterns seen in Table 4 become more apparent in this new experiment. We begin with TS and GT in Fig. 8. We see once again that wealth inequality and the net debtor population share evolve in opposite directions relative to the CEG. A striking result is the relationship between aggregate welfare and debt limits. The optimal debt limit $\underline{b}$ is located at zero — a result well-documented in Aiyagari economies, reflecting the price effect of debt described in Obiols-Homs (2011) and further characterized as a pecuniary externality in Dávila et al. (2012) and Nuño and Moll (2018). The negative impact of laxer debt limits is diminished by increasing the subsidy rate. A higher subsidy rate compresses the wealth distribution and shifts it to the right, generating an economy with relatively fewer borrowers, thus decreasing the impact of the

[44]In Section 3.2 we examine disaggregated measures of welfare.

[45]While we focus on general equilibrium in this paper, partial equilibrium results show that welfare gains from policy changes can more than double. For brevity, these results are not included but are available upon request.

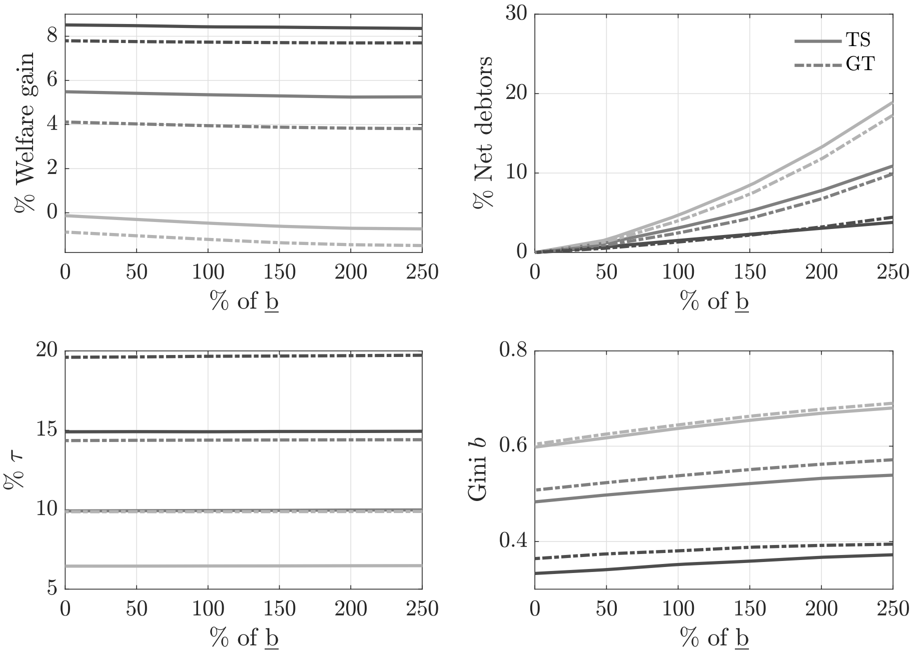

Fig. 8: CEG, wealth Gini, tax rate (τ_C^{GT} in GT) and net debtor share in TS and GT. Darker colors denote higher subsidy rates (50%, 75% and 100%).

price effect of debt.[46] Fig. 9 depicts the cases of ICL1 and ICL2, where we see that the direction of results go in the same way as in the previous experiment: there is lower aggregate welfare when the economy generates a larger mass of debtors and higher net debtor shares go hand in hand with larger wealth inequality.

The debt limit on student loans has a similar effect to that of the subsidy rate in Fig. 8 with the twist that the relationship between aggregate welfare and $\underline{a}$ in ICL2 is not monotonic - see Fig. 35 in the appendix. The aggregate welfare gain over NICL peaks at a student loan limit that is a bit larger than in the baseline. Gains remain positive but then dip as we increase in magnitude $\underline{a}$. Similar results have been found in the literature, Johnson (2013), Ionescu and Simpson (2016) and Abbott et al. (2019) identify a similar effect of student debt limits on welfare: laxer limits on a can provide diminishing gains or even drag down welfare - while more generous subsidies can generate stronger gains. Another remarkable result is the scale of the gains; note the magnitudes on the top left panels of Fig. 8, Fig. 9 and Fig. 35: welfare ranks consistently higher in TS and GT relative to ICLs.

There is no discernible relationship between aggregate welfare and the income tax rate. The income tax rate in ICLs can be as high as that of tuition subsidies. Furthermore, tax rates in ICL1 and ICL2 are not that different. However, in the former the government provides relatively more generous income-contingent support: it covers the interest *and amortisation* of agents that do not earn a high enough income. This occurs for two reasons. First, note that in ICL2 agents accumulate student loan interest when they do not earn enough. For a vast area of the state space, the tax r_p of earnings over the threshold z_T contributes little, if at all, to pay down the student loan balance. This can pose a larger burden on the public sector. Higher taxes and lower income-contingent protections in ICL2 explain why it delivers a smaller share of the population with a college degree. This takes us to the second point. ICL1 spends less in unemployment insurance, relative to ICL2 - see Table 4. As ICL1 delivers a larger share of college graduates, who face a better labour market (less unemployment), the cost of unemployment insurance drops, and more agents are able to pay down their student loan balances themselves, lowering the fiscal burden of the HE system. On aggregate, it is a better deal for the government to help

[46] In Section 3.2 we elaborate on this particular distributional impact of higher education reforms.

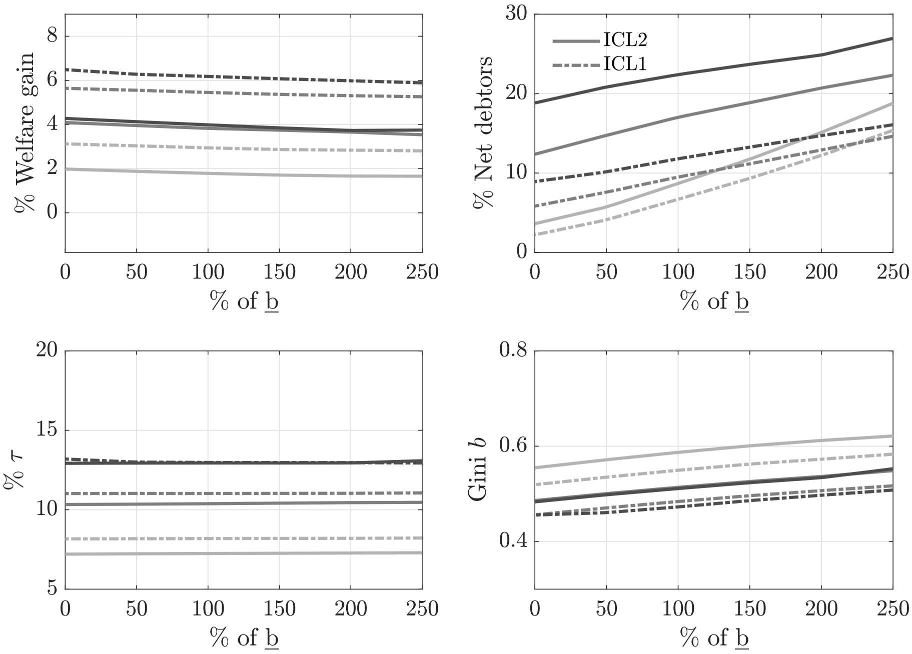

Fig. 9: CEG, wealth Gini, tax rate and net debtor share in ICL1 and ICL2. Darker colors denote larger student borrowing limits (50%, 100% and 150%).

bring down student loan balances of those that do not earn enough.

A critical distinction from Obiols-Homs (2011) lies in the interplay between debt limits and higher education financing reforms. While Obiols-Homs (2011) focuses purely on the welfare impact of debt limit changes, we quantify the effects of higher education reforms that induce broader effects and that may or may not involve changing debt limits. As the generosity of the higher education funding system increases, the wealth distribution shifts rightwards, its spread narrows, and the effective labour supply expands. This, in turn, raises interest rates and improves aggregate welfare. This stands in contrast to Obiols-Homs (2011), where larger debt limits are shown to increase the share of debtors and interest rates, reducing aggregate welfare. What is key between both studies is that policies that deliver more debtors tend to do worse and that welfare gains/losses can be compounded by the impact of equilibrium prices. One of the contributions of this paper, relative to Obiols-Homs (2011), is highlighting the importance of integrating education financing mechanisms into broader analyses of debt and welfare.

The cost of education

The relative rankings among financing systems are sensitive to the cost of education. Table 4, Table 5, Fig. 24 and Fig. 25 in the appendix show that when P is low- (50 % lower than in the baseline), the market failures in educational investment are not impactful enough to differentiate the outcomes among systems. Under these conditions, most systems deliver comparable welfare gains. However, as before, those systems achieving the lowest net debtor shares and wealth inequality emerge as the most favourable. Increasing the debt limit $\underline{b}$ consistently diminishes aggregate welfare gains across systems, reflecting the price effects discussed in Obiols-Homs (2011). In contrast, as illustrated in Table 4, Table 6, Fig. 26 and Fig. 27, a rise in education costs (50% higher than baseline) accentuates welfare disparities across financing systems. As Fig. 29 illustrates, tuition inflation in the United States has outpaced the growth of the CPI, healthcare, and housing costs. Although tertiary education costs per student are lower in Europe, many European countries have experienced a sharp rise in costs over the past decade. In this high-cost environment, differences in higher education financing schemes become more pronounced, with systems featuring tuition subsidies and graduate taxes demonstrating superior outcomes in terms of welfare gains, lower net debtor shares, and reduced wealth inequality. Furthermore, across all cost scenarios, ICL1, the more generous income-contingent student loan scheme, consistently outperforms ICL2.

In summary, variations of the debt limits $\underline{b}$, $\underline{a}$ and public funding generosity confirm that the price effect of debt and the relationship between aggregate welfare, net debtor shares and wealth inequality, are key determinants of the relative success of higher education financing schemes. The variations in P highlight how these effects become more pronounced as the cost of education increases. Furthermore, the sensitivity analysis presented above demonstrates that the rankings between systems remain robust. Higher values of P exacerbate capital market frictions and increase the risk associated with educational investments, thereby amplifying welfare gains as the generosity of the HE financing scheme increases. In all of the parameter configurations considered herein, TS and GT, subsidised at or close to 100% of educational costs, consistently yield larger steady state consumption equivalent gains (and lower debtor shares and wealth inequality) than in student loan systems.

3.2 Disaggregated CEG

A benefit of working with a heterogeneous agent model is that we can evaluate welfare gains due to higher education financing policies at each point of the state space. In this section we compare welfare gains by wealth deciles and by income/ability groups and assess the impact on welfare stemming from the equilibrium distributions of each system. The starting point of a disaggregate view of welfare gains begins by updating equation (29) so that we can get a measure of gains at each point in the state space

$$c(b, \tilde{a}, z, m) = \left[\left(\frac{V_c(b, a, z, m)}{V_o(b, a, z, m)} \right)^{\frac{1}{1-\sigma}} - 1 \right] * 100. \tag{30}$$

We use equation (30) to compare raw value functions (note that these results omit the effect of changes in the distribution), delivering results such as those in Fig. 10, where we compare the ICL1 welfare gains, relative to NICL, of four income/ability groups.[47] Results look broadly similar among all alternatives, albeit with different magnitudes of gains and losses. We begin by comparing NICL to ICL1.

Welfare gains are strongest for agents *without* a university degree (regardless of educational ability), particularly those with low wealth and high student debt balances. We emphasise that the agents that stand to gain the most are those that do not have a college degree, as it is generally considered that these are the agents that benefit the least from HE financing. As agents are forward looking and are now more likely to invest in education (for themselves or their offspring) and to influence the chances of their offspring's educational ability, non-graduates perceive the most gains from more generous public higher education financing. Additionally, the outflow of non-graduates towards graduates reduces the college wage premium, raising the labour income of these agents. Moreover, as agents are more likely to have a university degree, they are more likely to benefit from a labour market that has shorter unemployment spells, albeit with a lower college wage premium. Agents with large student loan balances also benefit from moving away from NICL, as income contingent-protections shield them from large interest payments, skills depreciation and college dropout risk. By reducing the risks associated with education, more agents are willing to pursue higher education, as reflected in the larger share of graduates shown in Table 4.

[47] As we have a large state space and menu of higher education systems, we focus on the four most important groups by population size (workers) for the sake of brevity. Comparisons of NICL versus TS and NICL versus ICL2 can be found in Fig. 32, Fig. 33 and Fig. 34 in the appendix.

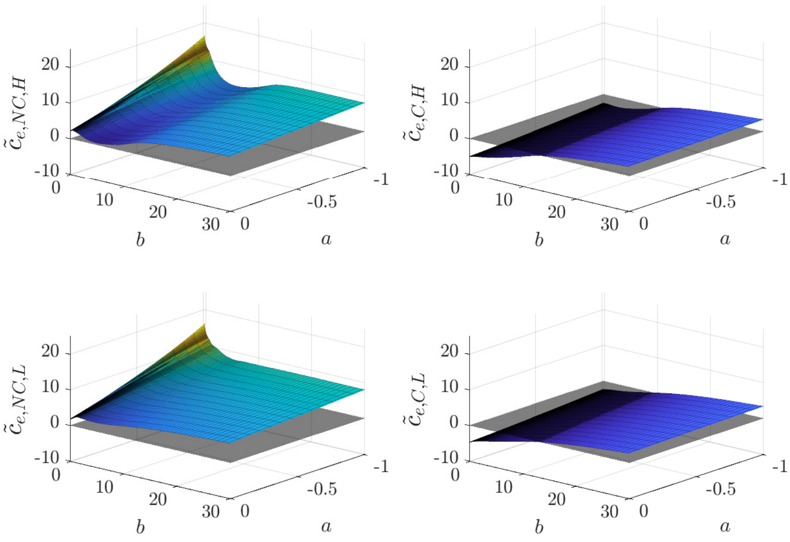

Fig. 10: Disaggregate welfare gains of ICL1 vs NICL. The first row depicts welfare gains relative to NICL for high educational ability workers without and with a university degree, respectively. The bottom row shows workers (without/with a degree) with low educational ability. The black surface represents zero welfare gains.

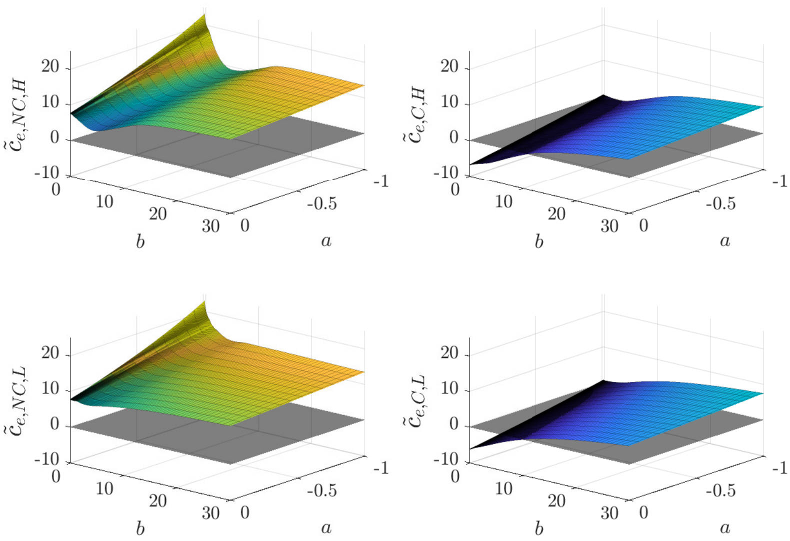

Fig. 11: Disaggregate welfare gains of GT 100 % vs NICL. The first row depicts welfare gains relative to NICL for high educational ability workers without and with a university degree, respectively. The bottom row shows workers (without/with a degree) with low educational ability. The black surface represents zero welfare gains.

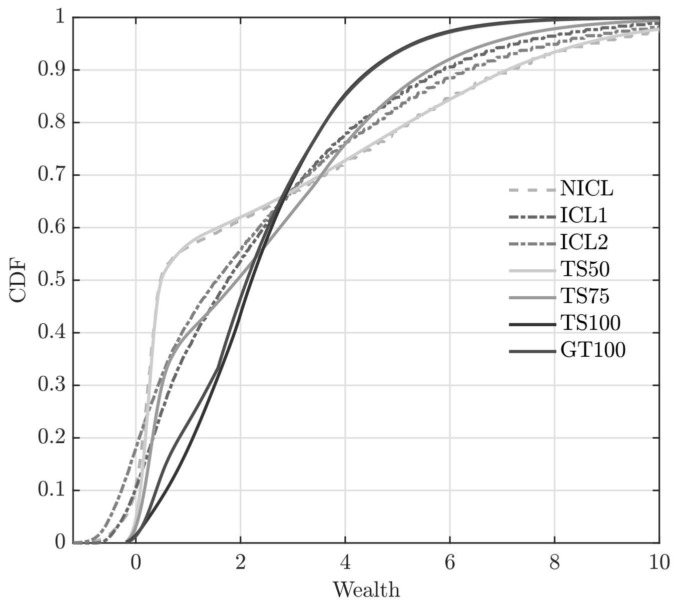

Fig. 12: Wealth CDF. Each HE system is coloured by its equilibrium interest rate; the darker the colour, the higher the equilibrium interest rate.

Agents with a university degree gain the least from the shift from NICL to ICL1. This is because university graduates must repay their student loans (as in NICL) while also competing with a larger proportion of university-educated workers, which reduces the college wage premium. The larger the graduate share, the worse off low-wealth university graduates become, as they rely more heavily on labour income. Conversely, high-wealth agents benefit from moving away from NICL, as they derive most of their income from wealth and gain from the higher equilibrium interest rate in ICL1. Similar results emerge when comparing NICL to ICL2, TS, and GT. If the alternative systems generate more lenders (less net debtors) than NICL, the resulting distributions of agents will enhance welfare gains. Hence, while raw value function comparisons provide insights into aggregate welfare, they must be complemented by an analysis of the new distributions. It is crucial to assess whether the new distribution places more weight on areas with positive or negative welfare gains. We elaborate on distributions further below.

Since the state space differs between NICL and systems without student loans (TS and GT), we compare the single-asset value function of GT with the value function at each level of student loans in NICL. Fig. 11 presents the results for NICL versus GT 100 %. The findings are similar to those observed when comparing NICL to ICL1, although in this instance the magnitude of gains is generally larger and loses are smaller for graduates with large student debt balances. The key question is how the new distribution under GT 100% reallocates mass relative to NICL, particularly across income groups and their positions within the wealth distribution. We therefore turn our attention to the role of the distribution in shaping welfare gains.

Impact of the distribution: Fig. 12 corroborates the results in Table 4: compared to NICL, all alternatives result in fewer debtors, reduced wealth inequality, and, in most cases, an increase in the capital stock. Notably, partial and full tuition subsidisation, whether funded through general taxation or graduate taxes, shifts the most mass towards moderately high levels of b and away from the extremes.[48] Given the debt cancellation offered in the income-contingent loan programmes, more agents will have no student loans balances in the ICLs than in NICL. As tuition subsidies (or income contingent-protections) increase, precautionary savings fall. Since

[48] Angelopoulos et al. (2017) report similar findings in a setting where education types are determined exogenously.

the distribution shifts more mass towards higher-income graduates, the capital stock rises despite the reduction in precautionary savings. This is reflected in the increase in mean wealth and the compression of the wealth distribution, becoming more pronounced as subsidy rates (or income contingent-protections) increase. This is analogous to how results would look if employment and skill depreciation transition rates were even more favourable for educated agents (if the risk of falling into bad states decreased). Furthermore, as higher education funding generosity increases, so does the graduate share. The resulting larger aggregate effective labour supply raises the equilibrium interest rate, as shown in Table 4.[49] Thus, the impact of the distribution extends beyond shifting mass to regions of the state space with positive welfare gains, as it also influences aggregate quantities and prices. More generous higher education policies lead to larger capital stocks *and* higher prices.[50]

Average welfare gains by income and ability groups: Next, we examine welfare gains across income and ability groups, using the NICL density to calculate group-specific welfare outcomes. We first focus on TS and GT, as varying their subsidy rates illustrate how the generosity of public funding amplifies gains and losses across different groups. Agents without a college degree, the first three groups in Fig. 13, experience the largest welfare gains, particularly those with high educational ability. In these three groups gains increase as the subsidy rate rises. Conversely, the last two groups, comprising unemployed and employed university graduates, perceive only modest gains when education is subsidised at 50% of its cost. However, they incur losses at subsidy rates of 75% and 100%, with the latter case showing the greatest losses. GT yields slightly greater welfare gains than TS for those without a college degree while mitigating losses for university graduates. Similar patterns emerge when comparing NICL with the ICLs in Fig. 14: the more generous the income-contingent student loan programme, the greater the welfare gains for the first three groups.

Average welfare gains by wealth decile: We now look at welfare gains in each wealth decile, where wealth is now defined as the sum of cash, b, and student loans, a. Fig. 15 shows that in all systems welfare gains are strongest for those that have wealth at or below the fifth decile. Furthermore, Fig. 16 reveals that within these deciles, at least 60% of agents experience non-negative welfare gains by moving from NICL to any alternative system (except TS 50%). The generosity of public funding further amplifies the welfare gains for the bottom five deciles, whereas the opposite effect is observed for most of the top wealth deciles. This pattern holds across ICLs, TS, and GT. Losses in the top deciles arise because they are calculated using the wealth distribution of NICL. As noted earlier, graduates with moderate wealth levels are the least likely to favour a shift away from NICL, as the alternative financing schemes reduce the college wage premium. Additionally, a similar result emerges as in the analysis of welfare gains by income and ability groups: GT amplifies welfare gains while mitigating losses more effectively than TS. While the magnitude of losses in ICLs is comparable to those in TS and GT, the welfare gains are more pronounced in the latter two systems. The fact that wealth rich agents gain less is unsurprising as the marginal utility of consumption is lower for these groups. However, a key takeaway is that low-wealth agents benefit more, as they are shielded from the risks associated with debt and failure in educational investments. Notably, the most substantial gains occur in the first decile, where all debtors are located.[51]

[49]These results align with Akyol and Athreya (2005), who find that subsidies reduce the risk of educational investments, lowering precautionary savings while increasing the equilibrium interest rate. The difference in the steady state equilibrium interest rate between NICL and the other systems is similar to those found in other studies (Akyol and Athreya (2005), Krueger and Ludwig (2016) and Heijdra et al. (2017)).

[50]This is reminiscent of Hanushek et al. (2003), where tuition subsidies increase welfare and reduce inequality in the presence of productive externalities from college-educated agents. While this model lacks direct productive externalities, increasing the graduate share relative to NICL yields similar benefits.

[51]The model likely underestimates the welfare gains of HE reforms due to its lower wealth Gini compared to U.S. data. The Floden decomposition in Fig. 6 reveals that most of the gains stem from reducing the costs

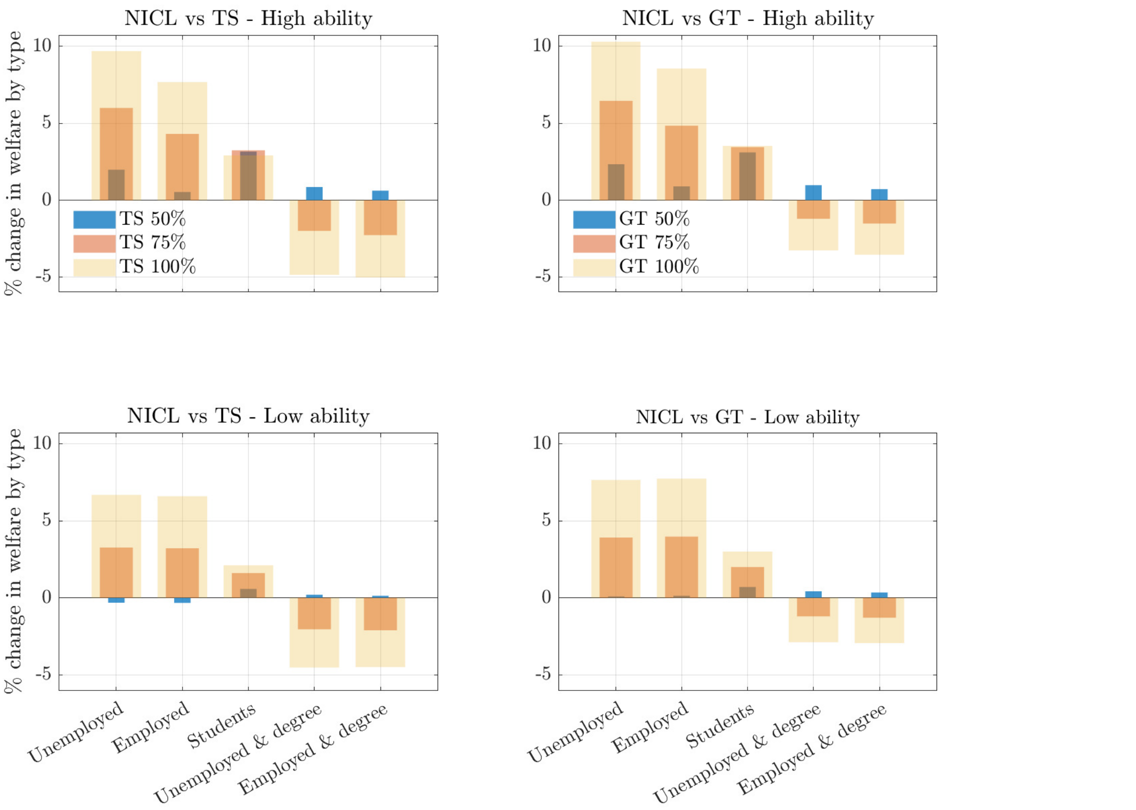

Fig. 13: Welfare gains over NICL, by income and ability groups, of tuition subsidies and graduate taxes

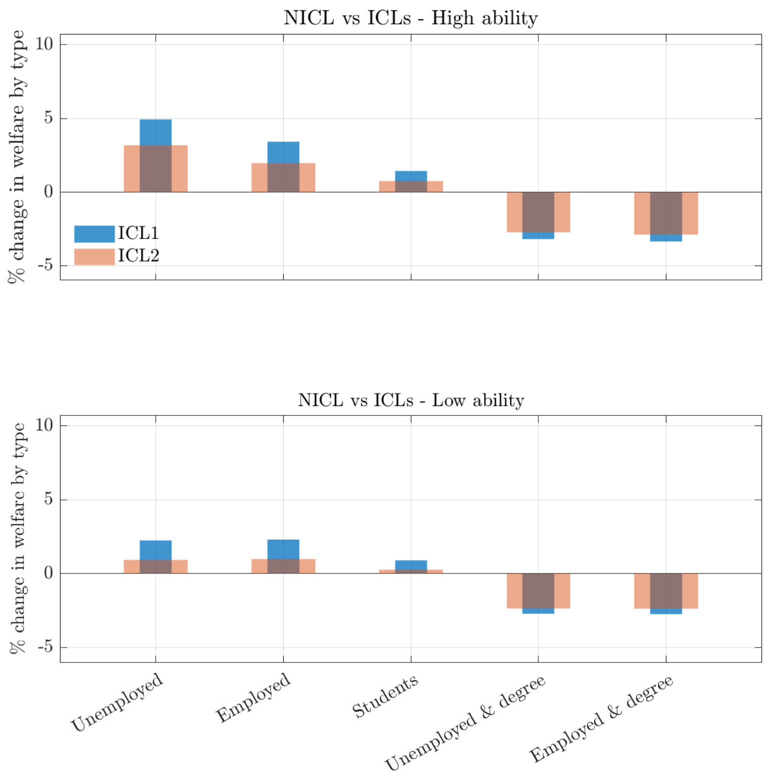

Fig. 14: Welfare gains over NICL, by income and ability groups, of income contingent loans 1 and 2

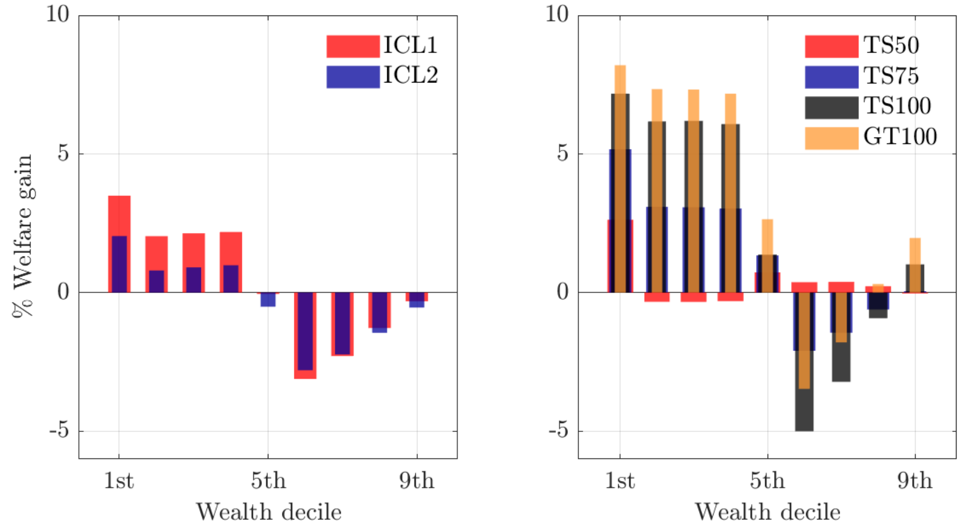

Fig. 15: Welfare gains over NICL, by wealth deciles

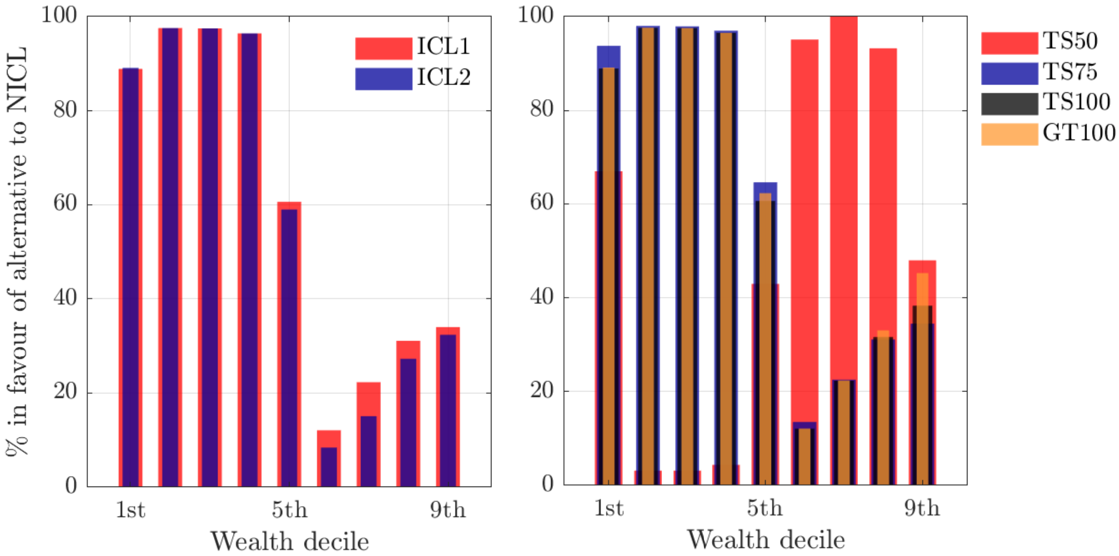

Fig. 16: Mass in favour of moving to alternative system, by wealth decile.

Mass in favour of change: Thus far, we have examined disaggregated welfare gains at specific points in the state space, as well as averages by income/ability groups and wealth deciles. In this subsection we assess which income/ability groups and wealth deciles are in favour of moving away from NICL. Specifically, we consider the proportion of the population within each subgroup that achieves at least non-negative welfare gains under any of the alternative higher education financing policies considered. Fig. 16 and Fig. 17 display the results from the perspective of income/ability groups and wealth deciles, respectively. Both figures point to similar conclusions: non-university graduates overwhelmingly support increased public funding for higher education, whether through income-contingent student loans or with subsidies (with or without graduate taxes). Excluding TS50%, differences in support due to funding generosity are minimal within the first three income groups (regardless of ability type) and the first four wealth deciles. Overall, TS and GT receive broader support and deliver larger gains than the ICLs, with GT minimising losses compared to TS.

of inequality. This component captures how the concavity of the value function and the distribution's shape jointly influence welfare outcomes. In a more unequal economy, the HE policies presented here could deliver even larger gains, especially with higher equilibrium interest rates, as these further increase the concavity of the value function, thus amplifying the benefits of reduced inequality.

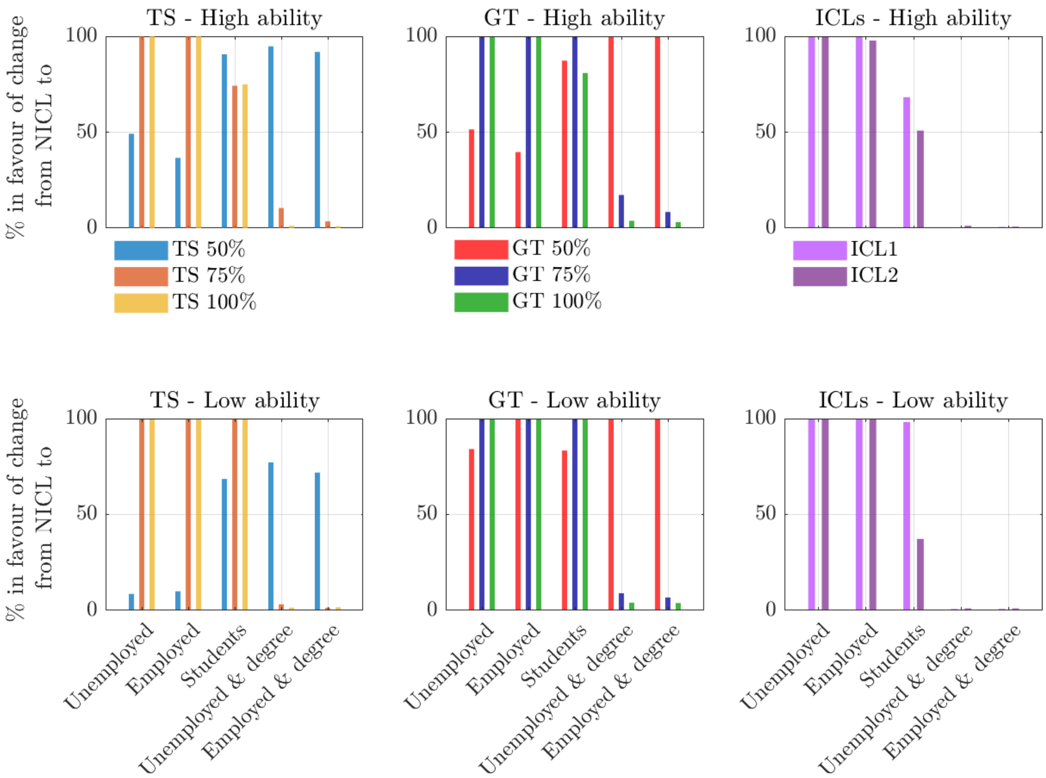

Fig. 17: Mass in favour of moving away from non-income-contingent loans, by group, towards tuition subsidies, graduate taxes and income contingent loans

4 Transitions

The five HE financing systems considered in this paper exhibit significant steady state welfare gains relative to NICL. Is it worth making the transition from NICL to any of them? This section aims to address that question. The next experiment considers an unexpected, immediate and permanent change of the higher education financing system.[52] We compute aggregate dynamic welfare gains in a similar fashion as in (28), although this time we use aggregate welfare an instant right after the transition begins

$$\tilde{c} = \left[\left(\frac{\hat{V_{t+\Delta}}}{\hat{V_t}} \right)^{\frac{1}{1-\sigma}} - 1 \right] * 100, \tag{31}$$

where

$$\hat{V_t} = \sum_m \sum_i \int_{\underline{a}}^0 \int_{\underline{b}}^\infty V(b, a, i, m, t) \mathrm{d}b\mathrm{d}a, \tag{32}$$

and where $\hat{V_t}$ and $\hat{V_{t+\Delta}}$ are the aggregate values before (NICL) and an instant after the policy change, respectively. Fig. 18 juxtaposes the static and dynamic (gains due to the transition) aggregate welfare gains while Fig. 19 and Fig. 20 show the transitional dynamics of key aggregates. There are two variants of the experiment when we move from NICL to TS or GT, where the transitions are done with or without the government absorbing all student loan bal-

[52]The computational approach used in this paper for the transitional dynamics is commonly referred to as "MIT shocks". See Achdou et al. (2022). Similar experiments, in which policy changes are announced in advance, yield lower gains as agents delay enrolling in university until the new system is implemented. This has negative aggregate effects given that it initially lowers $\theta_{e,C}$. A life-cycle formulation would dampen such an effect since the education choice will probably be made once in a single life time and sooner rather than later.

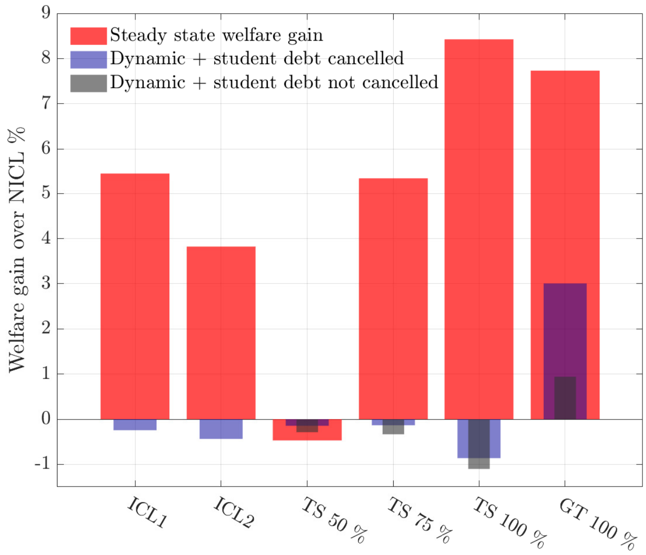

Fig. 18: Consumption equivalent gain of income contingent student loans 1 and 2 (ICL1 and ICL2), tuition subsidies (TS) and graduate taxes (GT) at 50, 75 and 100 % of educational costs, respectively. The gains are relative to the baseline (non-income-contingent student loans - NICL). Bars in red, purple and black represent steady state, dynamic with and without student loan cancellation, respectively.

ances.[53] In the former case, the government absorbs all student loans and continues making the same amortisation and interest payments as agents. In the latter case those that had student loans continue making payments as before but no more new student loans are issued once the transition begins.

Fig. 18 shows that steady state comparisons between systems can be misleading and that transitions are costly. Moving from NICL to ICLs results in small aggregate welfare losses, with dynamic aggregate welfare gains for ICL1 and ICL2 standing at -0.244% and -0.436%, respectively. Transitions from NICL to TS also yield aggregate welfare losses, and these increase in magnitude with larger subsidisation rates, regardless of whether the HE reform is combined with student debt cancellation. The gains of TS 50%, 75% and 100% are -0.146%, -0.135% and -0.863%, respectively. By contrast, the transition from NICL to GT 100% stands out, yielding a gain of 3.01%. Notably, the transition to TS 50% leads to a smaller loss relative to its steady state comparison, regardless of whether student debt cancellation occurs. Repeating these experiments without student debt cancellation produces broadly similar results, though aggregate welfare losses are amplified and gains are somewhat diminished. The impact of student debt cancellation is examined further below.

The transition paths of key aggregates, along with the previous results on borrowing limits and price effects of debt, illuminate why transitions deliver such rankings. Transitions are marked by considerable challenges, with all the adverse welfare indicators identified earlier becoming more pronounced in the initial years. Interest rates, the proportion of net debtors, and inequality all increase in the early stages of the transition. During this period, income declines and tax rates rise, largely due to heightened educational expenditures and a shrinking tax base as many workers enrol as students. The growing number of students eventually leads to an increase in graduates, which in turn reduces the college wage premium. Broadly speaking, most individuals experience lower incomes in the early years, and the benefits of the transition only materialise in the longer term. Since agents discount future benefits, they place greater emphasis on the

[53] This approach is motivated by two considerations. First, the prospect of debt cancellation along with a transition to a system without student loans is of policy interest. Second, it substantially reduces the computational cost of the transition as it allows us to drop one state variable.

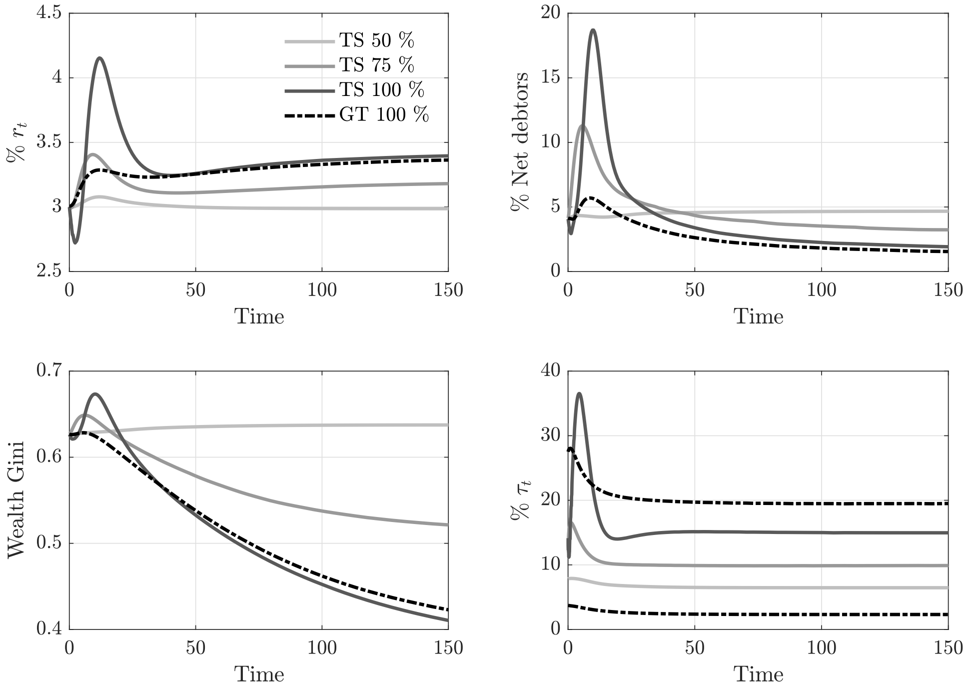

Fig. 19: Transition from benchmark (NICL) to tuition subsidised at different rates (TS) and fully funded graduate tax (GT). Dashed and solid lines in the bottom right panel depict graduate labour income taxes and non-graduate labour income taxes, respectively.

immediate costs of the transition than on its delayed advantages. As a result, even substantial steady state gains are overshadowed by the transition costs, making such policy changes less attractive when compared to steady state evaluations alone.[54]

The transitions from NICL to ICLs lead to moderate increases in interest and tax rates compared to tuition subsidies. The proportion of net debtors and levels of inequality exhibit greater fluctuations. The proportion of net debtors and level of inequality exhibit greater fluctuations. Due to a smaller influx of individuals pursuing graduate education, the college wage premium does not decline as sharply. The transition to GT is more effective in mitigating the early losses, as it shifts taxation exclusively onto college graduates, thereby moderating the influx of graduates and its subsequent impact on the college wage premium. Among the systems considered, the transition to GT results in the smallest increases in interest rates, inequality, the share of net debtors, and taxes for non-graduates. Consistent with the findings of Heijdra et al. (2017), we observe that while tuition subsidies and graduate taxes generate substantial aggregate welfare gains in steady state, tuition subsidies (graduate taxes) emerge as the least (most) favourable option during transitions.[55] Given that all systems display significant discrepancies between steady state and dynamic comparisons, which can even alter rankings, it is evident that policy

[54]Supply constraints in education and a more active fiscal policy would likely extend the shift of non-graduate workers to students over a longer period, thereby moderating transition costs. We did not include these features in the model to maintain tractability. Accordingly, the results presented in this paper could be viewed as a conservative estimate of the welfare gains from transitions.

[55]Age should act as a moderating factor in transitions, much like the graduate tax. In a life-cycle framework, agents are more likely to invest in education early in life, while middle-aged and older workers forgo education entirely. The reduced flow of non-graduates to students would dampen the initial spikes in interest rates, debt, tax rates, and inequality, thereby mitigating transition costs and enhancing welfare gains. However, older agents would likely bear more costs and derive limited benefits from the policy change, apart from the potential advantage of bequeathing wealth to younger agents, who now have a better opportunity to enrol in university. The overall magnitude of welfare gains would depend on the relative weight of each age group.

changes in higher education financing must account for the costs associated with transitions.

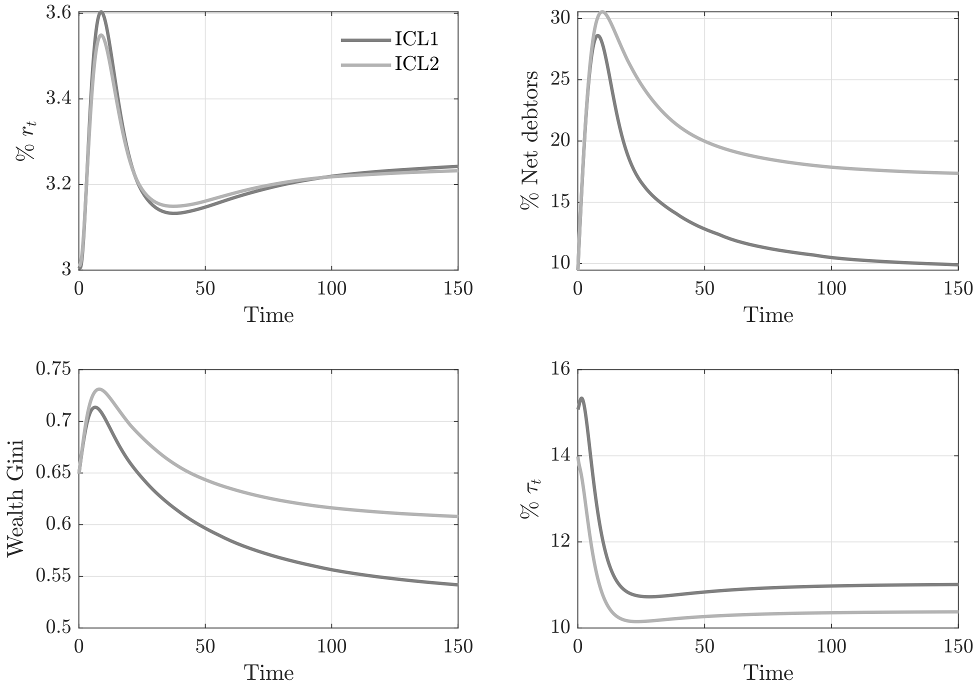

Fig. 20: Transition from benchmark (NICL) to income contingent loan systems (ICL1 and ICL2)

NICL to TS with and without student debt cancellation: In this subsection we analyse the impact of cancelling student debt when moving from NICL to TS[56]. We focus on the transition to TS 100%. Key aggregate outcomes are presented in Fig. 21, comparing transitions with and without student debt cancellation. When student loans are not cancelled there is a strong incentive for non-graduates with student debt to enrol at university. This is driven by two factors: the ability to defer student loan repayments and the avoidance of income taxation during their studies. The early years of the transition, marked by higher interest rates, make this option more attractive. The combination of reduced income tax revenue, due to the outflow of non-graduate workers becoming students, and increased educational expenditure drives the income tax rate higher than it would be under a scenario where student debt is cancelled. Additionally, the larger and more rapid increase in the graduate supply results in a sharper decline in the college wage premium. By contrast, when student loans are cancelled, the incentive to defer loan repayments is removed, leading to a more gradual inflow into higher education and a slower increase in the graduate supply. Moreover, the elimination of student debt reduces wealth inequality and decreases the proportion of the population in net debt, thereby mitigating the adverse effects of higher interest rates on net debtors. Consequently, the aggregate welfare loss associated with the transition is significantly greater when student debts are not cancelled.

[56]We gain similar conclusions from analysing transitions from NICL to GT or to TS at different subsidisation rates. For brevity, these results are omitted but are available upon request.

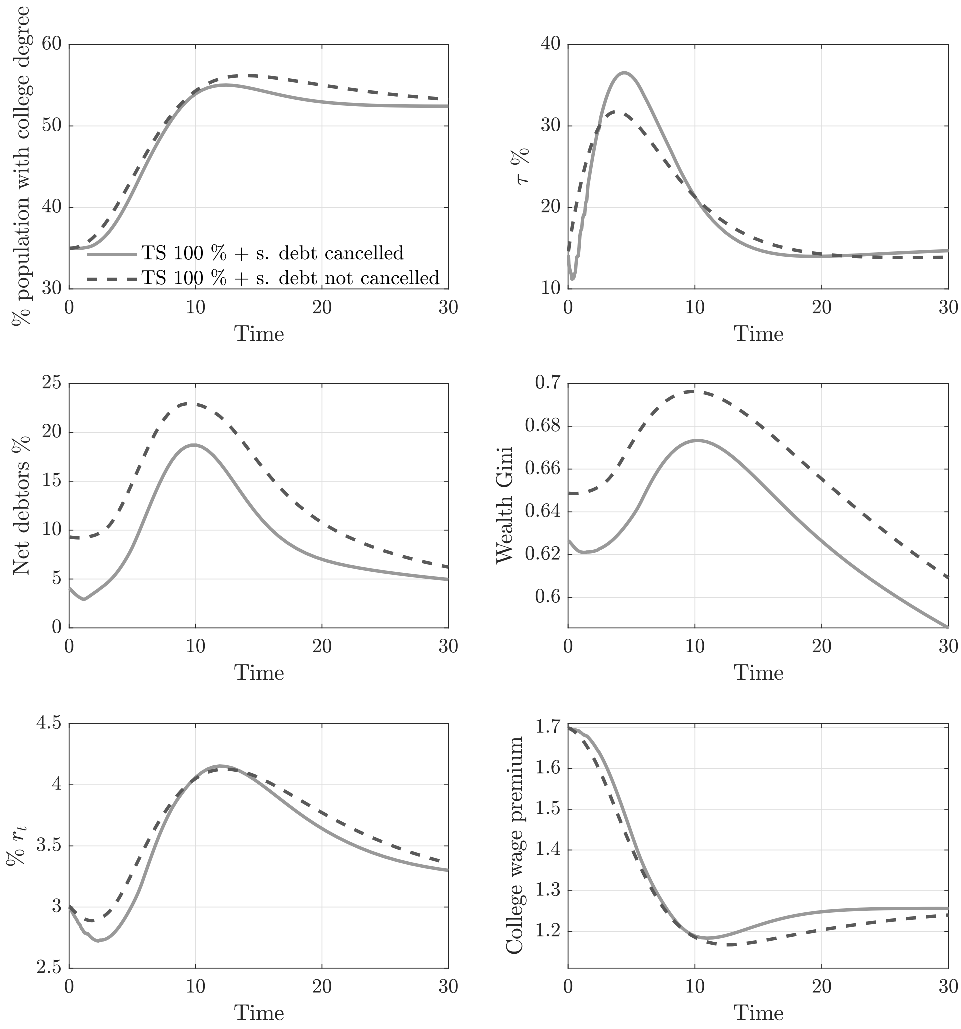

Fig. 21: Transition from benchmark (NICL) to TS 100 %

5 Policy relevance for Europe

The most relevant finding of this study for European policy making is the impact that the cost of education has on the rankings among different HE financing schemes. We have shown that when educational costs are small, differences in outcomes among systems are negligible (see Table 5). On the other hand, when education costs are similar to those we see in the United States, then the balance shifts in favour of subsidies, especially in the form of graduate taxes (see Table 4). Differences in welfare, inequality and educational attainment among systems are magnified as costs rise (see Table 6).

European countries have experimented with different ways of financing higher education. Countries like England, Wales and Northern Ireland have made a shift into income contingent loans. Many Continental European countries rely more heavily on grants and subsidies. Some have experimented with student loans, either as a top-up (for living expenses) or as a way of phasing out grants (for tuition). As Fig. 30 shows, tertiary education costs per student are lower in Europe. Hence, the variation in higher education financing schemes in Europe is justifiable, as this article predicts that differences in outcomes among financing schemes will be smaller in Europe. However, many European countries are experiencing rapid growth of costs per student (Fig. 31), which could magnify differences in outcomes from the various HE financing schemes considered in this paper.

Recent evidence from Europe shows that larger government support to education is associated with higher educational attainment and that in turn it leads to higher productivity, better labour market outcomes and greater intergenerational mobility (Vandeplas (2020)). Fiscal challenges and increasing inequality may nonetheless tempt policymakers to shift the burden of education towards students. In general, many countries have done this by introducing student loans with varying degrees of income-contingent protections. We show that the more students are protected from bad outcomes, the better the results that HE financing system delivers, both in terms of aggregates and for individuals. Moreover, we show that graduate taxes are superior to student loans in how they fulfill the need to reduce the fiscal burden of the higher education system, while shifting the costs to those who gain the most from a college degree. Finally, increases in automation and in longevity heighten the need of a higher education system where people can retrain throughout their lives. Student loan programs will be limited in their capacity, by debt limits and debt loads, whereas this is less of an issue with graduate taxes. Hence, in the midst of fiscal challenges, increasing longevity, advances in AI and rising education costs, graduate taxes appear as a more attractive policy choice than student loans for balancing equity and efficiency considerations.

6 Conclusion

This paper evaluates the welfare and inequality outcomes of five distinct higher education financing schemes, employing a heterogeneous agent model in continuous time. By incorporating endogenous educational choices, intergenerational transmission of educational skills, and early repayment of student loans, we systematically evaluate the impact that the most salient features of various educational systems (American, Continental European and that of England and Wales) have on welfare and inequality. This paper contributes to the literature on the macroeconomic and distributional impact of higher education financing in several key ways.

Firstly, we show that the welfare and inequality rankings among higher education financing systems depend critically on the cost of education. When education costs are relatively low, the market failures associated with educational investment are not impactful enough to differentiate the outcomes among systems. However, as education costs rise, reflecting trends observed in the United States and increasingly in Europe, the appeal of income-contingent loans and tuition subsidies grows, with subsidies funded by graduate taxes yielding the largest welfare gains and reductions in inequality.

Second, one of the contributions of this paper is highlighting the importance of integrating education financing mechanisms into broader analyses of debt and welfare. This analysis underscores the necessity of considering the price and quantity effects of debt, as higher education financing systems that produce a high proportion of net debtors often exhibit greater inequality and diminished welfare.

Furthermore, the paper highlights the importance of transition costs. While steady state comparisons suggest considerable welfare gains from higher education financing reforms, the short-term disruptions associated with the transition from one regime to another often offset these gains. We calibrate the the model to the United States, where the government provides a student loan facility and partially subsidises the cost of education and compute various aggregate and disaggregate measures of consumption equivalent gains from changing higher education financing. Our results indicate that, despite lower welfare gains during the transition relative to the steady state, tuition subsidies funded by graduate taxes deliver the largest aggregate welfare gains, amounting to a 3.01% increase in consumption-equivalent terms. These findings suggest that policymakers must weigh the immediate burdens of transitions against their long-term advantages.

The broader policy implications for Europe are clear. As education costs rise, the differences between financing systems become more pronounced. This calls for a shift towards systems that subsidise education and that are funded with graduate taxes, which balance equity and efficiency considerations more effectively than loan-based systems. Moreover, rising costs, demographic shifts, and technological advancements necessitate a financing framework that enables lifelong learning and retraining. Systems relying heavily on student loans may falter under these pressures, whereas susbsidies funded though graduate taxes may provide a more robust solution.

This study has scope for further exploration. Future research should disaggregate the college wage premium, as recent UK-based studies (Belfield et al. (2018a), Belfield et al. (2018b), and Britton et al. (2020)) have shown that, while the average premium has remained stable, or even increased, it is largely driven by substantial heterogeneity and extreme outliers. These studies highlight that the returns to higher education vary significantly by subject, institution, and individuals' gender. How should higher education be funded when the distribution of returns is highly skewed? Another promising extension would be to examine how increased longevity and rising exposure to automation risk might necessitate repeated investments in education and greater government support for higher education. Would longer life expectancy encourage more individuals to retrain and return to university at older ages?

7 Appendix

7.1 Kolmogorov forward equations

Let g represent the density, ∂_k denote the partial derivative w.r.t. k and the subscripts in g depict the agent type. Let m and $-m$ denote the ability types. The Kolmogorov Forward Equation (KFE) of unemployed agents without a college degree is given by

$$\partial_t g^m_{u,NC} = -\partial_a[S^m_{a,u,NC} g^m_1] - \partial_b[S^m_{b,u,NC} g^m_1] + \lambda_{eu,NC} g^m_{e,NC} - (\lambda_{ue,NC} + \kappa) g^m_{u,NC} + \lambda^S_{x,m} g^m_s + \lambda^U_x g^m_{u,C} + \chi^m_{u,NC}, \tag{33}$$

where $b < b^{m,\dagger}_1(a)$. The KFE of employed agents without a college degree is

$$\partial_t g^m_{e,NC} = -\partial_a[S^m_{a,e,NC} g^m_2] - \partial_b[S^m_{b,e,NC} g^m_2] + \lambda_{ue,NC} g^m_{u,NC} - (\lambda_{eu,NC} + \kappa) g^m_{e,NC} + \lambda^E_x g^m_{e,C} + \chi^m_{e,NC}, \tag{34}$$

where $b < b^{m,\dagger}_2(a)$. The KFE of students, unemployed and employed agents with a college degree are

$$\partial_t g^m_s = -\partial_a[S^m_{a,s} g^m_s] - \partial_b[S^m_{b,s} g^m_s] - [\lambda^S_{x,m} + \lambda_{su,C} + \lambda_{se,C} + \kappa] g^m_s + \chi^m_s, \tag{35}$$

$$\partial_t g^m_{u,C} = -\partial_a[S^m_{a,u,C} g^m_4] - \partial_b[S^m_{b,u,C} g^m_{u,C}] + \lambda_{su,C} g^m_s + \lambda_{eu,C} g^m_{e,C} - [\lambda^U_x + \lambda_{ue,C} + \kappa] g^m_{u,C} + \chi^m_{u,C}, \tag{36}$$

$$\partial_t g^m_{e,C} = -\partial_a[S^m_{a,e,C} g^m_{e,C}] - \partial_b[S^m_{b,e,C} g^m_{e,C}] + \lambda_{se,C} g^m_s + \lambda_{ue,C} g^m_{u,C} - [\lambda^E_x + \lambda_{eu,C} + \kappa] g^m_{e,C} + \chi^m_{e,C}. \tag{37}$$

where χ^m_i captures the re-injection of mass due to death (newborns), skills depreciation shocks and student loan cancellation and flows from non-graduates to students.[57] In steady state $\dot{g} = 0$ for all b, a, i, m. In single asset regimes we drop the dependence on a.

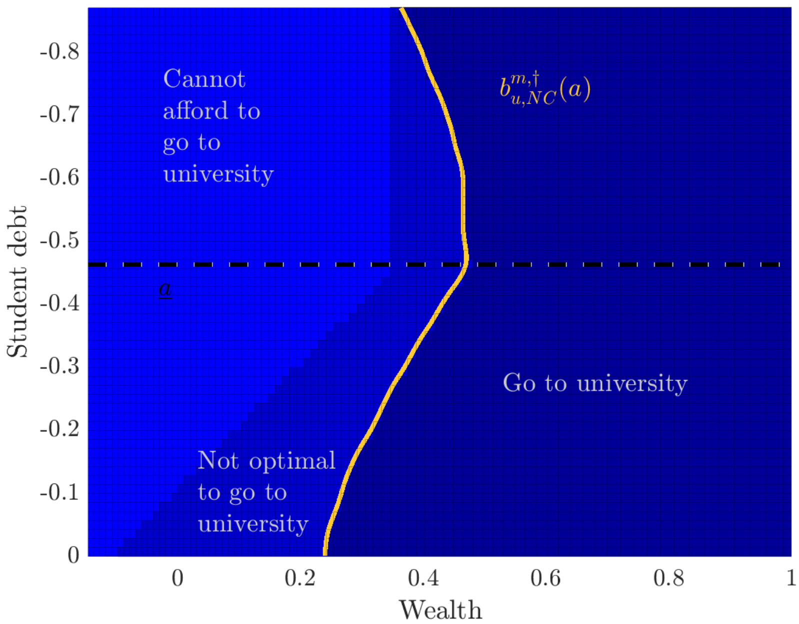

Fig. 22: Decision map of unemployed agents without a college degree and with high educational ability in NICL, overlaid with, $\underline{a}$, the student debt limit.

[57]Note that inflows to $g^m_{u,NC}$ and $g^m_{e,NC}$ beyond their respective boundaries $b^{m,\dagger}_i(a)$ are immediately redirected to $g^m_s(b^*, a^*)$.

Before elaborating on each χ_i^m, let's recall some notation with the help of Fig. 22. For each agent type and for each value of student loans, there is a free boundary $b_i^{m,\dagger}(a)$ that determines when the agent chooses to become a student. Once an agent reaches a level of wealth b larger than $b_i^{m,\dagger}(a)$ then it is immediately moved to the student type with new values of wealth and student loans $(b_i^{m,*}(b,a), a_i^{m,*}(b,a))$. We suppress the notational dependence of (b^*, a^*) on state variables for the sake of exposition, except when we describe χ_s^m. Any agent that dies or gets hit with skill depreciation or college drop out shocks, with wealth beyond $b_i^{m,\dagger}$, is immediately replaced (or substituted by newborn in the case of death) as a student with new values of wealth (b^*, a^*). We now expand on each χ^m. We define $\chi_{u,NC}^m$ as

$$\begin{aligned}\chi_{u,NC}^m = \kappa\delta(a)\left(\sum_i \lambda_{i,m}^m g_i^m + \sum_i (1-\lambda_{i,-m}^{-m}) g_i^{-m}\right)\mathbb{1}_{\{b>0\}} + \lambda_{np} g_{u,NC}^m[\delta(a)-1] \\ + \kappa\delta(b)\delta(a)\left(\sum_i \lambda_{i,m}^m g_i^m + \sum_i (1-\lambda_{i,-m}^{-m}) g_i^{-m}\right)\mathbb{1}_{\{b\leq 0\}}. \end{aligned} \tag{38}$$

The first and third terms represent the introduction of newborns to the *unemployed and no college degree* state, where they are born with non-negative assets b and zero student loan balance a. The first term captures the inflow of newborns that inherit positive values of wealth. Newborns whose parents died with debt in b are born with zero wealth (the third term). Note how the inflow of newborns takes into account the intergenerational transmission of educational ability, which is influenced by the educational status and ability of parents.[58] The Dirac deltas $\delta(a)$, $\delta(b)$ direct mass to regions where $a = 0$ and $b = 0$, respectively. The second term accounts for student loan cancellations (outflows from all a's and inflows towards $a = 0$), which direct mass towards $a = 0$.

We will need a bit more notation for χ_s^m. Let b' and a' denote wealth and student loan balances of an agent right before getting hit with a shock that would make her immediately enrol at university.[59] We define χ_s^m as follows:

$$\begin{aligned}\chi_s^m = &\left[\lambda_{x,m}^S g_s^m(b',a') + \lambda_x^U g_{u,C}^m(b',a')\right]\mathbb{1}_{\{b_{u,NC}^{m,*}(a^*(b',a'))\geq b_{u,NC}^{m,\dagger}(a^*(b',a'))\}} \\ &+ \lambda_x^E g_{e,C}^m(b',a')\mathbb{1}_{\{b_{e,NC}^{m,*}(a^*(b',a'))\geq b_{e,NC}^{m,\dagger}(a^*(b',a'))\}} \\ &+ \lambda_{np} g_s^m(b,a)[\delta(a)-1] \\ &+ \kappa\delta(a)\left(\sum_i \lambda_{i,m}^m g_i^m(b',a') + \sum_i (1-\lambda_{i,-m}^{-m}) g_i^{-m}(b',a')\right)\mathbb{1}_{\{b>0\}}\mathbb{1}_{\{b_{u,NC}^{m,*}(a^*(b',a'))\geq b_{u,NC}^{m,\dagger}(a^*(b',a'))\}} \\ &+ \kappa\delta(b)\delta(a)\left(\sum_i \lambda_{i,m}^m g_i^m(b',a') + \sum_i (1-\lambda_{i,-m}^{-m}) g_i^{-m}(b',a')\right)\mathbb{1}_{\{b\leq 0\}}\mathbb{1}_{\{b_{u,NC}^{m,*}(a^*(b',a'))\geq b_{u,NC}^{m,\dagger}(a^*(b',a'))\}}. \end{aligned} \tag{39}$$

Note that we now make the dependence of (b^*, a^*) on b' and a' explicit. The first terms are inflows from college dropouts and unemployed graduates that got hit with a skills depreciation shock and that have sufficient wealth to become students once again. The second term captures college graduates in employment hit with a skill depreciation shock and that have enough wealth to become students once again. The third term tracks student loan cancellations (outflows from

[58] See Section 7.4 on the appendix, which elaborates on ability transition rates and the intergenerational transmission of ability.

[59] We use this notation since we need to track the wealth and student debt values (before tuition costs) of agents that get hit with shocks that push them to values above $b_i^{m,\dagger}(a)$.

all a's and inflows towards $a = 0$), which direct mass towards $a = 0$. The fourth and fifth terms are the inflow of newborns that have sufficient wealth to become students. The fifth term is the inflow of mass coming from agents born with no wealth (whose parents died with debt).[60] The remaining χ_i^m terms capture student debt cancellation

$$\chi_i^m = \lambda_{np} g_i^m(b,a)[\delta(a) - 1], \quad \text{for } i = e_{NC}, u_C, e_C. \tag{40}$$

7.2 Market clearing

In this subsection we develop a heuristic proof showing that $K_S = K_D$ implies $Y = C + I +$ Education costs. The same steps can be applied to any regime and will lead to the same conclusion. For the sake of brevity, we illustrate this with the TS regime. Without loss of generality and for the sake of brevity, assume that $\underline{b} = 0$ and that there are three groups of agents (numbered 1,2 and 3 for ease of notation): non-graduate workers, students and graduates in employment.[61] As there is no unemployment insurance, labour income taxes are levied to cover education expenses only. Non-graduates can become students if they have enough wealth and find it optimal to do so. It takes on average $1/\lambda_{23}$ years to graduate and college graduates receive skill depreciation shocks at rate λ_x. Students drop out of college at rate λ_s Agents die at rate κ. Let $\tilde{P} = P(1-s)$, the cost of education that an agent faces after tuition subsidies. Let g and s represent the density and drift of wealth for each agent type, respectively. The KFEs of the reduced model are

$$\begin{aligned}
\partial_t g_1(b) &= -\partial_b[s_1(b)g_1(b)] + \lambda_s g(b) + \lambda_x g_3(b) + \kappa(g_2(b) + g_3(b)), \quad \text{for } b < b^\dagger, \\
\partial_t g_2(b) &= -\partial_b[s_2(b)g_2(b)] - (\lambda_{23} + \lambda_s + \kappa)g_2(b) + (\lambda_s + \lambda_x + \kappa)\left[g_2(b+\tilde{P}) + g_3(b+\tilde{P})\right]\mathbb{1}_{\{b > b^\dagger - \tilde{P}\}}, \\
\partial_t g_3(b) &= -\partial_b[s_3(b)g_3(b)] + \lambda_{23} g_2(b) - (\lambda_x + \kappa)g_3(b).
\end{aligned}$$

Following Nuño and Moll (2018), we start with the aggregate law of motion of capital

$$K = \sum_i \int_{\underline{b}}^{\infty} b g_i(b) \mathrm{d}b,$$

where the time derivative is given by

$$\frac{\mathrm{d}}{\mathrm{d}t} K = 0 = \sum_i \int_{\underline{b}}^{\infty} b \partial_t g_i(b) \mathrm{d}b \quad \text{(in steady state)}.$$

We plug the KFE on the right hand side and proceed to the following result.

$$\begin{aligned}
\sum_i \int_{\underline{b}}^{\infty} b \partial_t g_i(b) \mathrm{d}b = &- \sum_i \int_{\underline{b}}^{\infty} b \partial_b[s_i(b)g_i(b)] \mathrm{d}b + \int_{b^\dagger - \tilde{P}}^{\infty} b\left[(\lambda_s + \kappa)g_2(b+\tilde{P}) + (\lambda_x + \kappa)g_3(b+\tilde{P})\right] \mathrm{d}b \\
&- \int_{b^\dagger}^{\infty} b\left[(\lambda_s + \kappa)g_2(b) + (\lambda_x + \kappa)g_3(b)\right] \mathrm{d}b \mathrm{d}b.
\end{aligned}$$

Simplifying terms we obtain

[60] If debt limits are large enough to meet tuition costs an agent could enrol in university with zero wealth.

[61] Instead of tracking the free boundary by employment state, student loan balance and ability type, which quickly gets messy, we solve a smaller version where there is only one free boundary $b^\dagger$.

$$
\begin{aligned}
\sum_i \int_{\underline{b}}^{\infty} b\partial_t g_i(b)\mathrm{d}b = & -\sum_i b s_i(b) g_i(b)|_{\underline{b}}^{\infty} + \sum_i \int_{\underline{b}}^{\infty} s_i(b) g_i(b)\mathrm{d}b \\
& - P(1-s)\int_{b^{\dagger}}^{\infty} \left[(\lambda_s+\kappa)g_2(b) + (\lambda_x+\kappa)g_3(b)\right]\mathrm{d}b.
\end{aligned}
$$

The first term on the right hand side is equal to zero. We now expand the second term. Let θ_i denote the share in the population of the ith type of agent.

$$
\sum_i \int_{\underline{b}}^{\infty} s_i(b) g_i(b)\mathrm{d}b = \theta_1 w_{NC}(1-\tau) + \theta_2 z_s w_{NC} + \theta_3 w_C(1-\tau) + rK^S - C.
$$

We plug the expression of the income tax rate of the reduced model $\tau = \text{Ed costs}/(\theta_1 w_{NC} + \theta_3 w_C)$ to obtain

$$
\begin{aligned}
\sum_i \int_{\underline{b}}^{\infty} s_i(b) g_i(b)\mathrm{d}b = & w_{NC}[\theta_1 + \theta_2 z_s] + \theta_3 w_C + \left(\frac{\alpha Y}{K^D} - \delta\right) K^S - C \\
& - sP\int_{b^{\dagger}}^{\infty} \left[(\lambda_s+\kappa)g_2(b) + (\lambda_x+\kappa)g_3(b)\right]\mathrm{d}b.
\end{aligned}
$$

We can simplify further

$$
\begin{aligned}
\sum_i \int_{\underline{b}}^{\infty} s_i(b) g_i(b)\mathrm{d}b = & (1-\alpha)\frac{Y}{\tilde{L}^{\nu}}\left(\chi[\theta_1 + \theta_2 z_s] + (1-\chi)\theta_3\right) + \left(\frac{\alpha Y}{K^D} - \delta\right) K^S - C \\
& - sP\int_{b^{\dagger}}^{\infty} \left[(\lambda_s+\kappa)g_2(b) + (\lambda_x+\kappa)g_3(b)\right]\mathrm{d}b, \\
\sum_i \int_{\underline{b}}^{\infty} s_i(b) g_i(b)\mathrm{d}b = & (1-\alpha)Y + \left(\frac{\alpha Y}{K^D} - \delta\right) K^S - C \\
& - sP\int_{b^{\dagger}}^{\infty} \left[(\lambda_s+\kappa)g_2(b) + (\lambda_x+\kappa)g_3(b)\right]\mathrm{d}b.
\end{aligned}
$$

The last step tells us that if $K_S = K_D$, we recover the national income identity. Putting everything together, along with setting capital supply equal to capital demand yields the expression for law of motion of aggregate capital, which in steady state is equal to zero.

$$
\begin{aligned}
\frac{\mathrm{d}}{\mathrm{d}t}K = 0 = & Y - \delta K - C - P\int_{b^{\dagger}}^{\infty} \left[(\lambda_s+\kappa)g_2(b) + (\lambda_x+\kappa)g_3(b)\right]\mathrm{d}b \\
\frac{\mathrm{d}}{\mathrm{d}t}K = 0 = & Y - I - C - \text{Education costs.}
\end{aligned} \tag{41}
$$

7.3 Portfolio problem and pecking order

An earlier version of this model allowed agents to maximise V_s by choosing how to pay P with the best feasible combination of b and a in the NICL, ICL1 and ICL2 regimes. The results are similar to the ones presented here. Only very wealthy agents choose to pay for university out of their savings b. This motivated the use of a so-called 'pecking order' mechanism to model the decision of how to cover P when becoming a student. This is computationally less expensive. Note however that agents are free to repay their student loan balances early at any point in time (thus adjusting their holdings of b and a). An example of how the pecking order works when deciding to become a student is shown in Fig. 23.

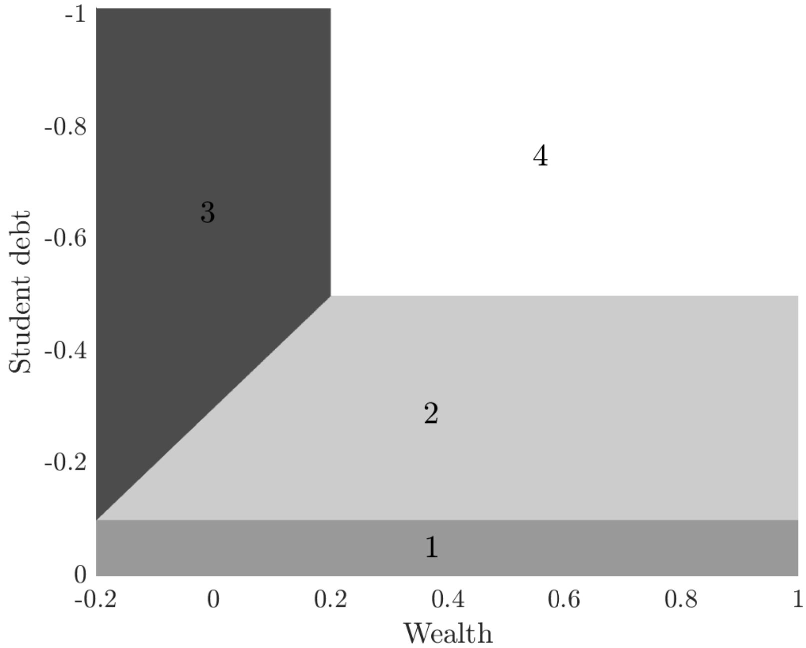

Fig. 23: 1 - Cover tuition with a only. 2 - Cover tuition with mix of b and a. 3 - Cannot afford to go to university. 4 - Cover tuition with b only.

Suppose that $P = 0.4$, $\underline{a} = -0.5$, $\underline{\underline{a}} = -1$ and $\underline{b} = -0.2$. The agent will first try to cover P exclusively with student loans, a situation depicted in region 1. If the agent has more than 0.2 in student loans, it will only be able to afford tuition costs by maxing the difference between a and $\underline{a}$ in new student loans, and covering the rest with b. This case is that of region 2. If the agent has limited b and a large stock of a, then it will not be able to go to university, the case of region 3. Finally, if the agent has a stock of student loans at or beyond $\underline{a}$, it will only be able to afford tuition costs with b.

7.4 Intergenerational transmission of ability

The transition matrix of the parental transmission of ability is based on a reduced (2×2) version of the ability transition matrix in Abbott et al. (2019). That is, we restrict ourselves to two ability types. The intergenerational transmission of ability depends on the parents ability and on its education status, thus yielding the following (4×2) transition probabilities.

$$\begin{bmatrix} 0.6571 & 0.3429 \\ 0.7360 & 0.2640 \\ 0.7414 & 0.2586 \\ 0.6218 & 0.3782 \end{bmatrix} \tag{42}$$

The first column is the probability that the offspring is born with the same ability as that of its parent. The second column is the probability that the child is born with a different ability. The first two rows correspond to high educational ability parents; the first and second rows depicting the probabilities by education type, no college and college education, respectively. The third and fourth rows are analogous to the first two rows, but this time recording the probabilities that a low educational ability parent will have a low or high educational ability child.

7.5 Benchmark calibration of P, debt limits and z_T

7.5.1 Cost of education P

In 2018 U.S. GDP per capita stood at $54541 according to the World Bank. We calibrate P to the average cost of attending university (tuition, room and board), taking into account, following Athreya et al. (2019), that around 60% of students enrol in public universities and the remaining 40% in private universities and also taking into account that, according to NCES (2018), about a quarter of students enrol in out of state universities.[62] The cost of public and private universities is taken from College Board (2018), where the average annual cost of an American public and private non-profit four year university in 2018 was $21370 (in-state tuition, room and board - $37430 out-state) and $48510 (tuition, room and board), respectively. The average cost of attendance, $34635, is rescaled to GDP per capita. We reweigh GDP per capita by the number of working age people in the U.S., as the model does not account for those who are not of working age. The U.S. Bureau of Economic Analysis reports that U.S. population reached 328.795 million while the OECD estimates that the working age population in the U.S. stood at 206.538 million in 2018. The benchmark calibration of P is set to

$$P = \frac{34635 \frac{1}{\Delta_{ed}}}{\frac{328.795}{206.538} * 54541} Y. \tag{43}$$

Given that Y is an endogenous variable the cost of education is updated at every market clearing loop. The sensitivity analysis in P, which involves changing the numerator of (43), gives further indication of how each higher education regime fares as we change the relative cost of education.

7.5.2 Debt limits

We compute debt limits $\underline{b}$ as shown next. Following the same reasoning as above and converting the debt limit figure from the 2019 Survey of Consumer Finances we obtain a debt limit $\underline{b}$

$$\underline{b} = \frac{20571}{\frac{328.795}{206.538} * 54541} \bar{Y}, \tag{44}$$

which is equal to -0.1872.[63] As mentioned in the calibration section, the total aggregate federal student loan limit in the U.S. for independent undergraduate students in 2018 was $57500. We use this value to compute $\underline{a}$

$$\underline{a} = \frac{57500}{\frac{328.795}{206.538} * 54541} \bar{Y}. \tag{45}$$

Note that we use $\bar{Y}$ to indicate that this values is fixed; it is the steady state output of the baseline, NICL.

7.5.3 ICL2 income threshold z_T

The Plan 2 student loan repayment threshold of England and Wales stood at £21000 in 2018.[64] The average GBP/USD exchange rate for 2018 is 1.3363 while the ratio of population to workers

[62] The cost of education is difficult to pin down since it is not obvious to what extent we should include room and board expenses. It is not clear what percentage of students move out of home when they enrol at university. For simplicity it is assumed that all students face tuition, room and board costs. We still perform a sensitivity analysis on P, which allows us to see how results would change if we had weighed the average cost of education considering that some students do not face room and board costs.

[63] The value of mean credit limit $20571 is estimated from the 2019 SCF, following Athreya et al. (2019) and converting to 2018 dollars.

[64] Plan 2 student loans are those issued in England or Wales from September 2012 onwards. https://www.gov.uk/guidance/previous-annual-repayment-thresholds

is 66.46/41.253 according to Board of Governors of the Federal Reserve System and the OECD, respectively. According to the World Bank, UK GDP per capita in 2018 stood at $42992 in 2022 dollars. After converting this figure to 2018 dollars we get an estimate of $37567.76. We thus compute z_T as follows:

$$z_T = \frac{21000 * 1.3363}{\frac{66.46}{41.253} * 37567.76} \bar{Y}. \tag{46}$$

Unlike the computation of P, we do not update Y at every market iteration loop in z_T. Instead we use the baseline (NICL) steady state output $\bar{Y}$.

7.6 Results when P is lower/higher than the benchmark

When the price of education is low, the market imperfections in educational investment lessen, reducing differences among the various higher education financing systems considered in this paper. Also, we see smaller welfare gains relative to NICL. As shown in Table 5 the CEGs over NICL are very small when we cut the cost of education by 50%. The difference in the amount of graduates among HE systems is smaller than in the baseline. We observe in Table 6 that differences in welfare gains and educational attainment are magnified when the cost of education rises.

7.6.1 Low cost of education

Table 5

	NICL	ICL1	ICL2	TS50 %	TS75 %	TS100 %	GT100 %
CEG	0	3.408	2.470	0.552	3.040	4.673	3.835
K	2.480	2.466	2.459	2.489	2.489	2.479	2.444
$\tilde{L}$	0.444	0.454	0.451	0.446	0.453	0.458	0.450
r	3.141	3.355	3.333	3.149	3.264	3.374	3.360
Graduates %	42.425	48.450	46.516	43.012	47.556	51.727	45.687
τ %	4.681	7.846	7.095	4.806	6.454	8.394	11.479*
τ_{UI} %	2.389	2.212	2.239	2.287	2.224	2.164	2.251
Gini$_{b+a}$	0.544	0.464	0.519	0.518	0.442	0.363	0.378
Net debtors % $b+a$	4.486	5.852	11.222	2.757	2.157	1.528	1.397
Net debtors % b	1.309	1.644	2.139	2.757	2.157	1.528	1.397
CWP	1.490	1.346	1.391	1.477	1.367	1.272	1.411
High ability %	49.143	50.713	50.345	49.469	50.253	51.052	50.003

Steady state general equilibrium results when the cost of education is halved. In GT we have two tax rates; * is τ_C^{GT} and τ_{UI} is τ_{NC}^{GT}.

Fig. 24, Fig. 25, Fig. 26 and Fig. 27 illustrate that the rankings based on steady state consumption equivalent gains (relative to NICL at the new cost of education), and its relationship with net debtors and inequality are robust to different debt limits in b and a. As the cost of education rises, welfare differences among systems become more patent.

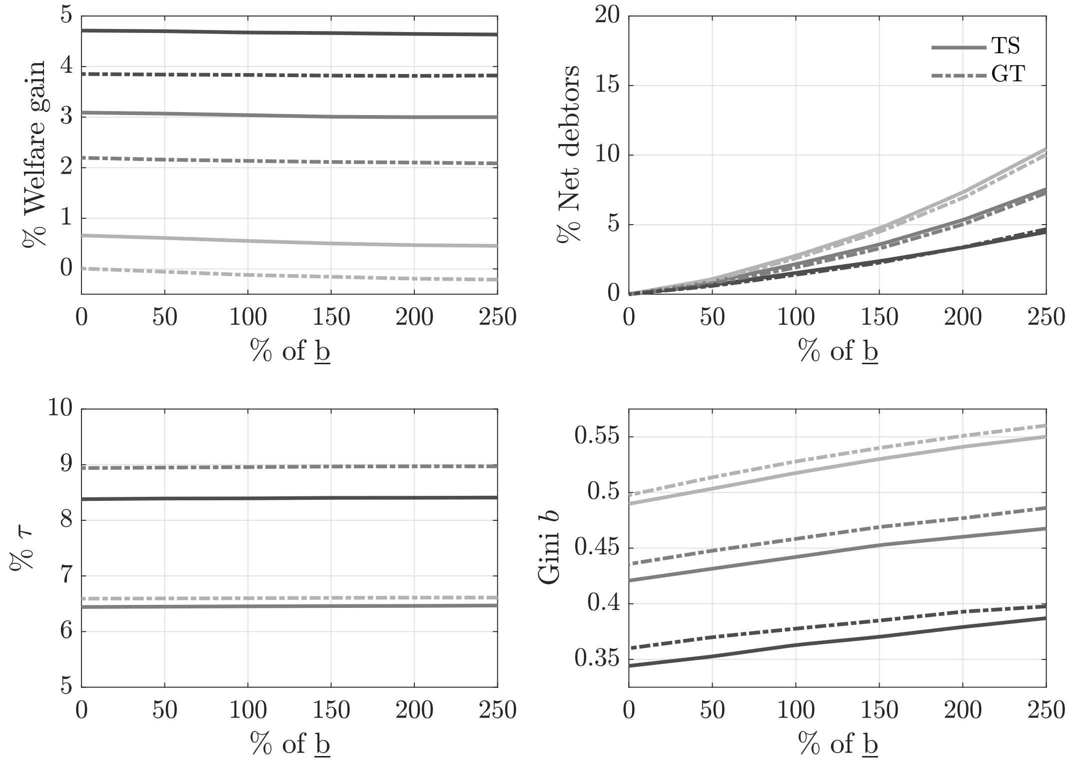

Fig. 24: CEG, wealth Gini, tax rate (graduate income tax) and net debtor share in TS and GT when education costs fall by 50 %. Darker colors denote larger subsidy rates (50%, 75% and 100%).

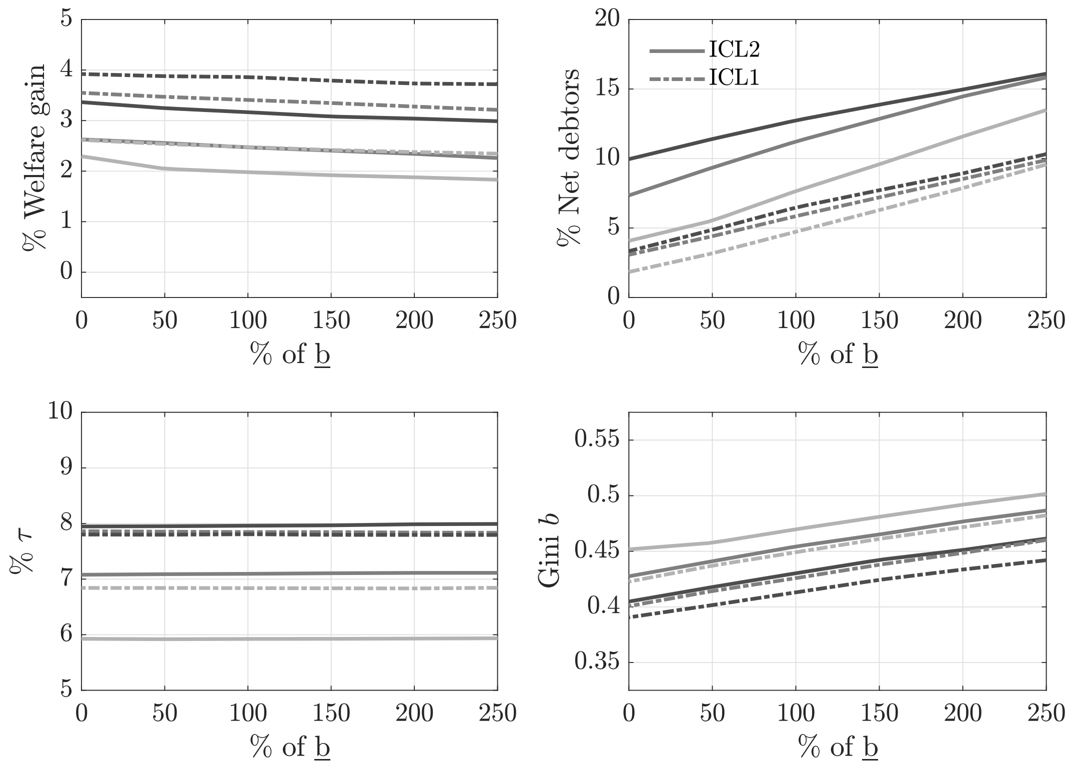

Fig. 25: CEG, wealth Gini, tax rate and net debtor share in ICL1 and ICL2 when education costs fall by 50 %. Darker colors denote larger student borrowing limits (50%, 100% and 150%).

7.6.2 High cost of education

Table 6

	NICL	ICL1	ICL2	TS50 %	TS75 %	TS100 %	GT100 %
CEG	0	6.504	5.322	-1.238	7.733	11.925	12.799
K	2.249	2.426	2.403	2.359	2.451	2.448	2.323
$\tilde{L}$	0.388	0.430	0.425	0.406	0.438	0.459	0.433
r	2.867	3.057	3.048	2.834	3.134	3.507	3.448
Graduates %	27.811	35.098	33.211	26.434	39.271	53.960	36.238
τ %	5.988	11.315	10.697	7.123	12.582	21.788	26.659*
τ_{UI} %	2.561	2.447	2.467	2.578	2.410	2.130	2.377
Gini$_{b+a}$	0.693	0.616	0.659	0.725	0.587	0.345	0.377
Net debtors % $b+a$	10.077	10.157	15.896	7.312	4.400	1.468	1.230
Net debtors % b	5.593	4.548	5.102	7.312	4.400	1.468	1.230
CWP	1.925	1.697	1.757	2.009	1.574	1.223	1.664
High ability %	46.825	48.371	48.102	46.925	48.747	51.483	48.393

Steady state general equilibrium results when the cost of education rises by 50 %. Welfare gains relative to NICL increase; in this case the gap in welfare gains in TS and GT with subsidy rates above 50% widens vis-à-vis ICLs (relative to those in Table 4). In GT we have two tax rates; * is τ_C^{GT} and τ_{UI} is τ_{NC}^{GT}.

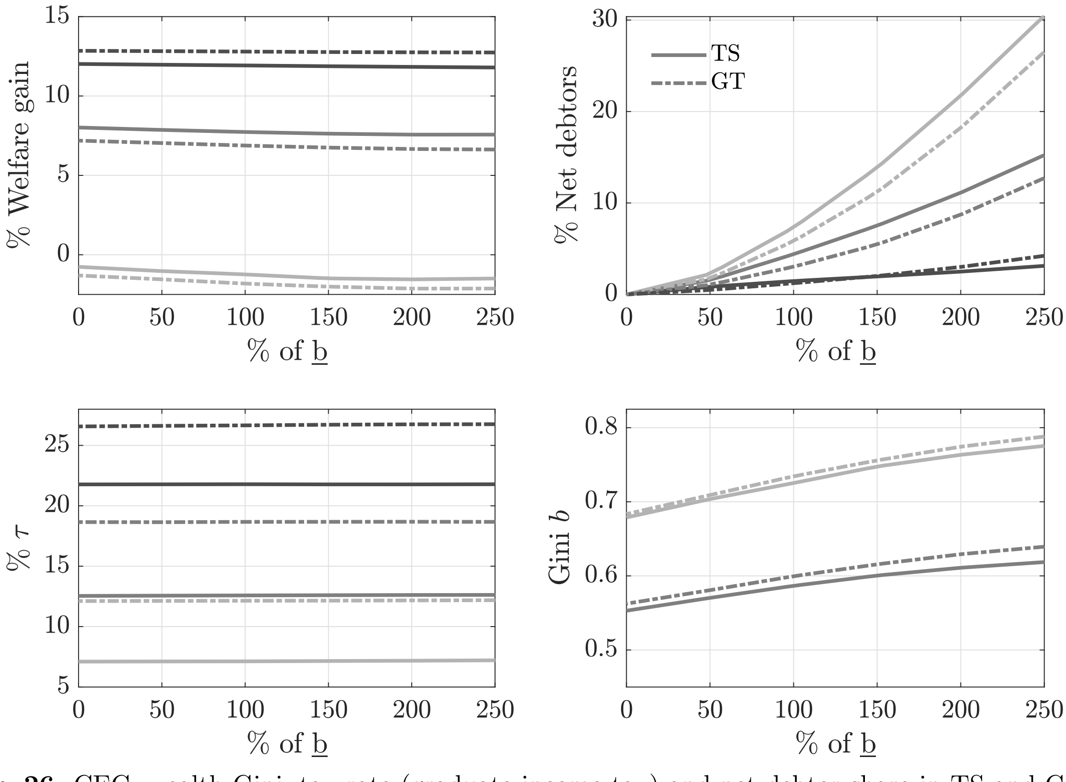

Fig. 26: CEG, wealth Gini, tax rate (graduate income tax) and net debtor share in TS and GT when the benchmark cost of education rises by 50 %. Darker colors denote larger subsidy rates (50%, 75% and 100%).

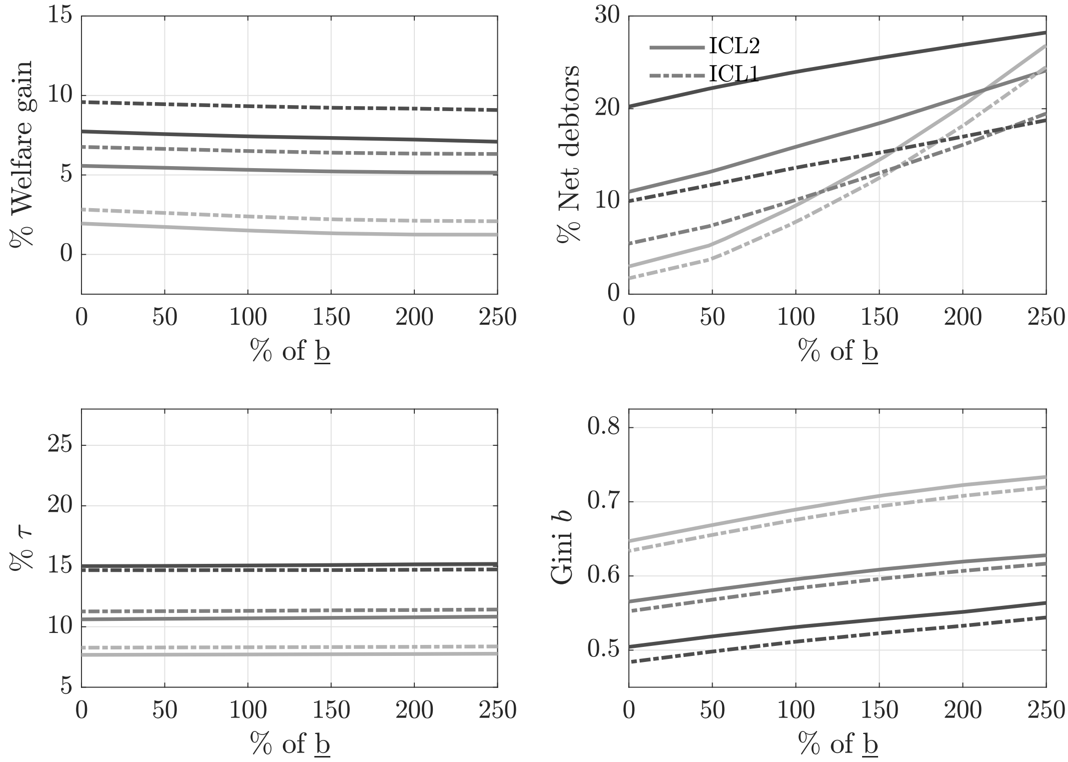

Fig. 27: CEG, wealth Gini, tax rate and net debtor share in ICL1 and ICL2 when the benchmark cost of education rises by 50 %. Darker colors denote larger student borrowing limits (50%, 100% and 150%).

7.7 Additional tables and figures

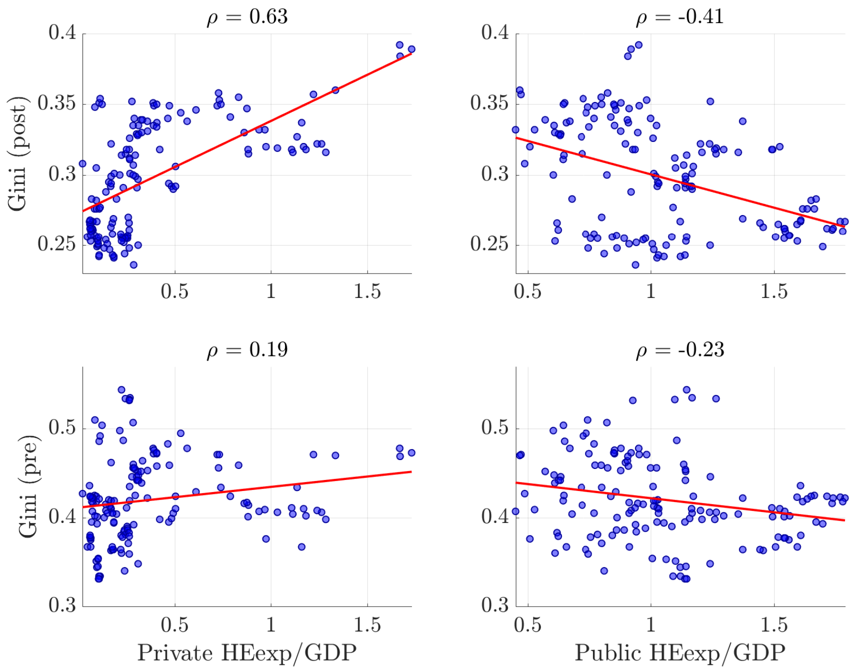

Fig. 28: Working age income Gini (post and pre redistribution) vs HE expenditure relative to GDP and its correlation during 2000-2016 in the following countries: AUS, AUT, CAN, CZE, DEU, DNK, ESP, EST, FIN, FRA, GBR, GRC, IRL, ISL, ISR, ITA, JPN, KOR, LUX, NLD, NOR, NZL, PRT, SVK, SVN, SWE, USA. Source: OECD.

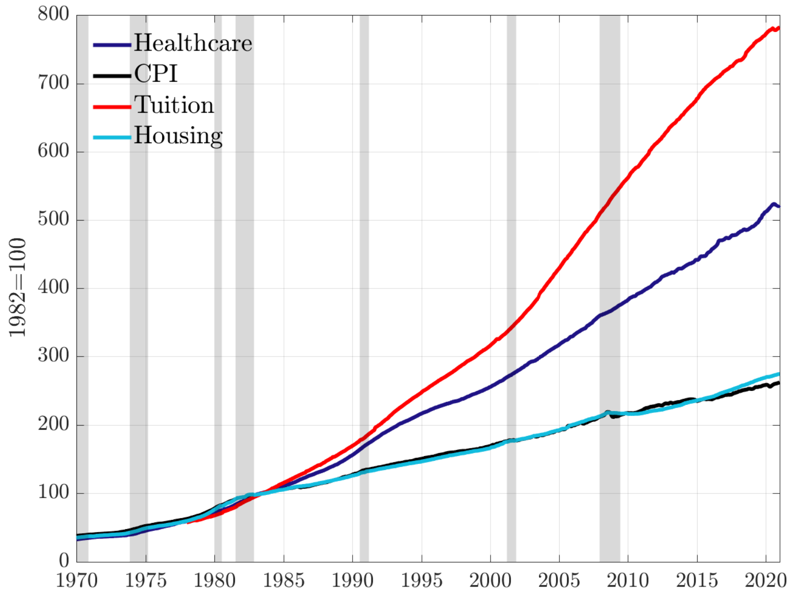

Fig. 29: Tuition inflation. Source: U.S. Bureau of Labor Statistics (2020)

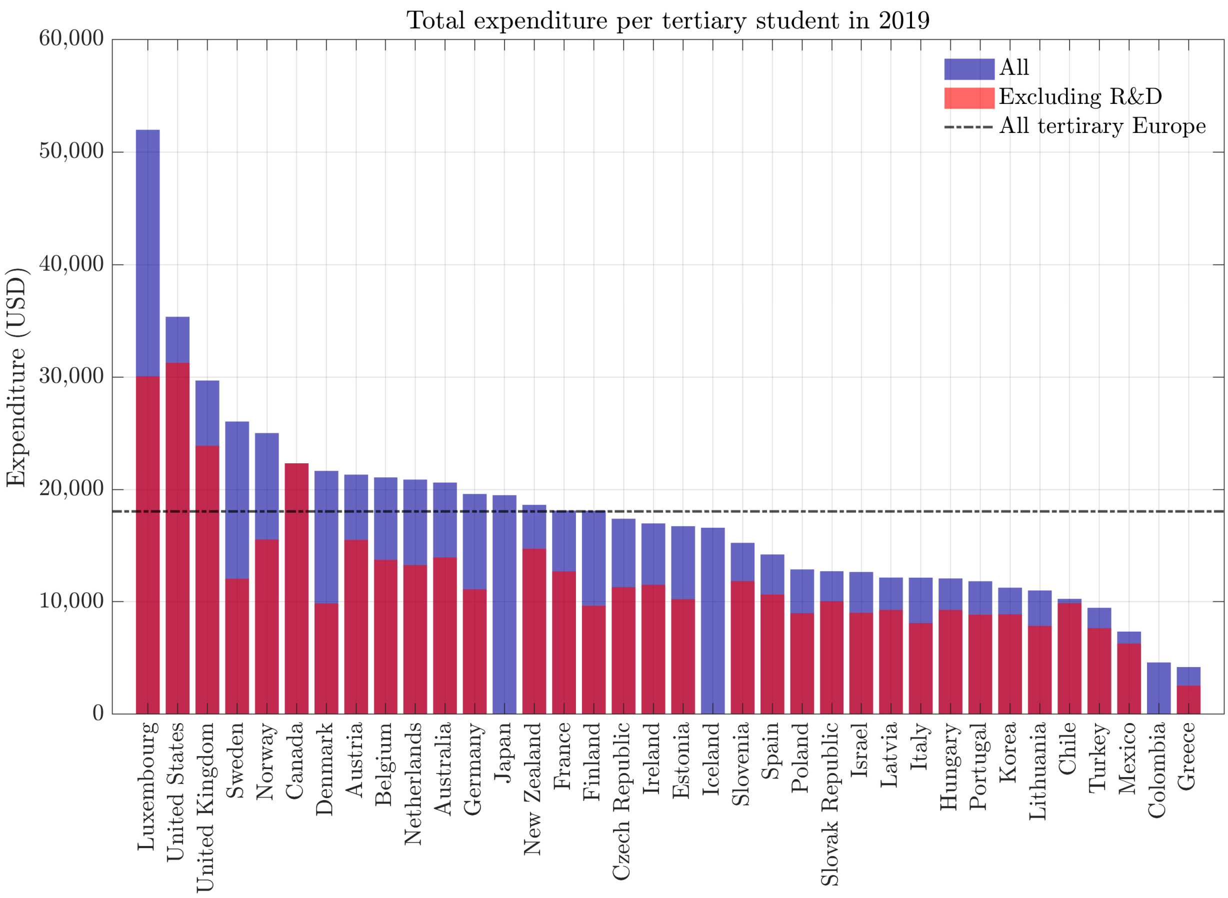

Fig. 30: Total expenditure per full-time equivalent student (2019) in tertiary education, in equivalent USD converted using PPPs for GDP and direct expenditure within educational institutions. There is no data available for expenditure excluding R&D for Japan, Iceland and Colombia. The Europe average is composed of Luxembourg, Germany, Austria, Belgium, Netherlands, France, Italy, Spain, Portugal, Slovak Republic, Slovenia, Finland, Czech Republic, Hungary, Poland, Estonia, Latvia, Lithuania, Greece, Ireland, Sweden, Norway, Iceland, Denmark, United Kingdom and Turkey. Source: OECD.

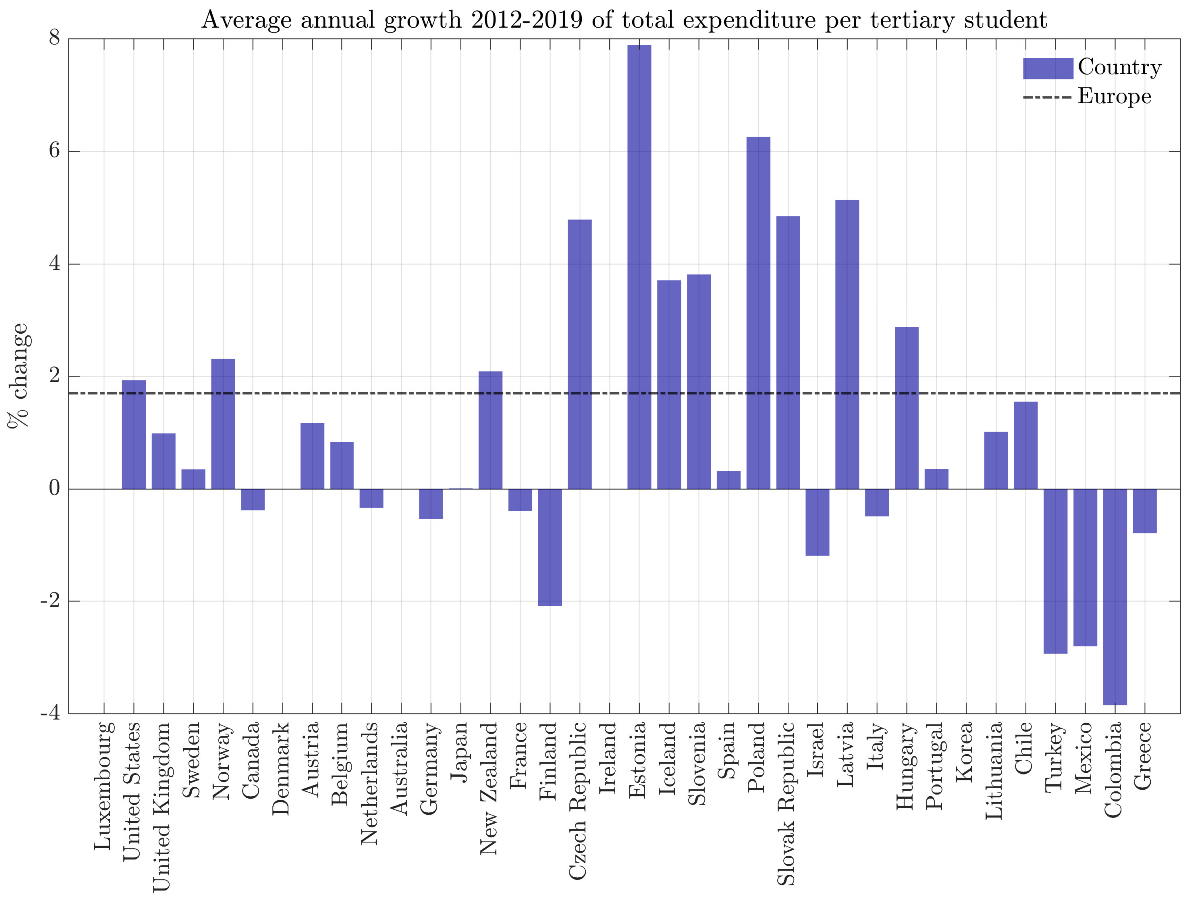

Fig. 31: Annual average growth in 2012-2019 of total expenditure per full-time equivalent student in tertiary education. There is no data available for Luxembourg, Denmark, Australia, Japan, Ireland and Korea. The Europe average is composed of Luxembourg, Germany, Austria, Belgium, Netherlands, France, Italy, Spain, Portugal, Slovak Republic, Slovenia, Finland, Czech Republic, Hungary, Poland, Estonia, Latvia, Lithuania, Greece, Ireland, Sweden, Norway, Iceland, Denmark, United Kingdom and Turkey. Source: OECD.

7.7.1 Disaggregated welfare NICL versus TS and ICL2

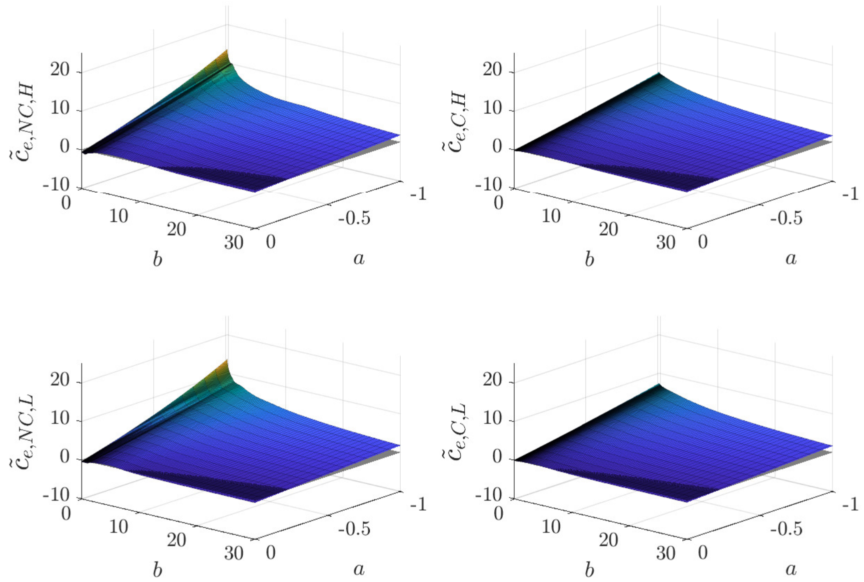

Fig. 32: Disaggregate welfare gains of TS 50% vs NICL. The first row depicts welfare gains relative to NICL for high educational ability workers without and with a university degree, respectively. The bottom row shows workers (without/with a degree) with low educational ability. The black surface represents zero welfare gains.

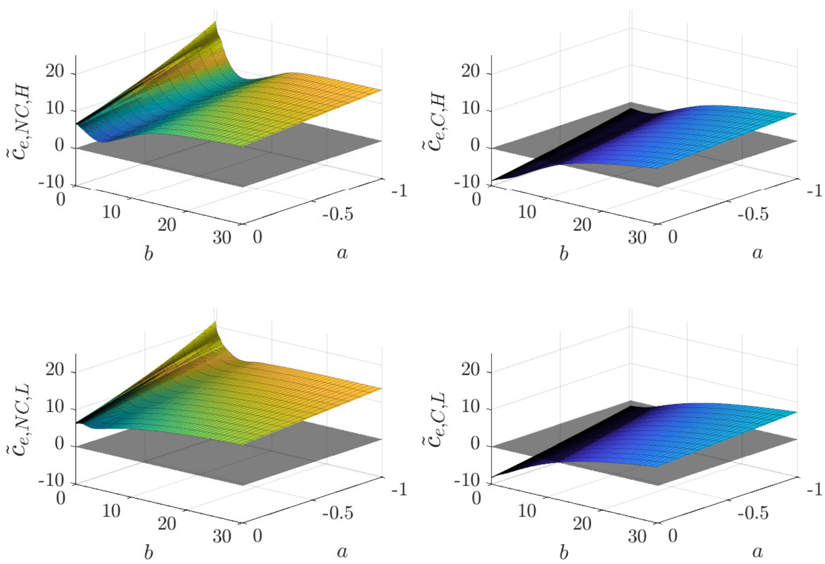

Fig. 33: Disaggregate welfare gains of TS 100% vs NICL. The first row depicts welfare gains relative to NICL for high educational ability workers without and with a university degree, respectively. The bottom row shows workers (without/with a degree) with low educational ability. The black surface represents zero welfare gains.

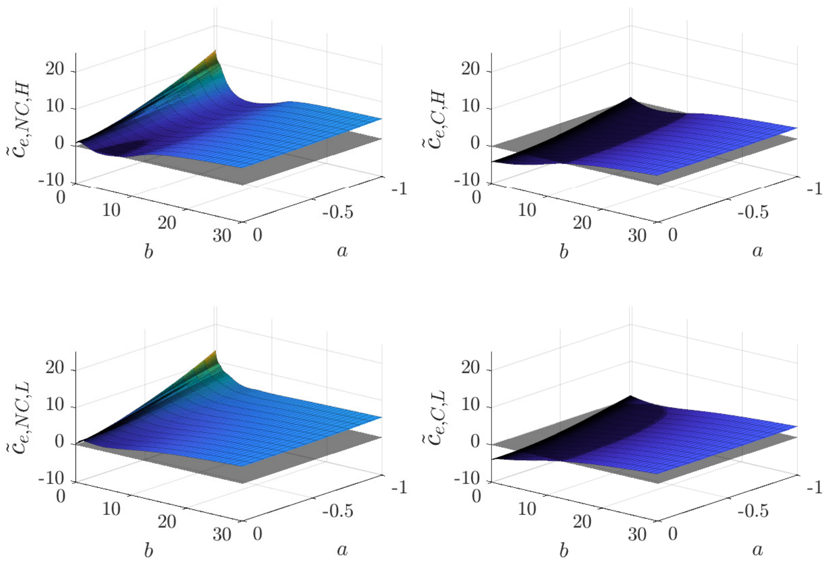

Fig. 34: Disaggregate welfare gains of ICL2 vs NICL. The first row depicts welfare gains relative to NICL for high educational ability workers without and with a university degree, respectively. The bottom row shows workers (without/with a degree) with low educational ability. The black surface represents zero welfare gains.

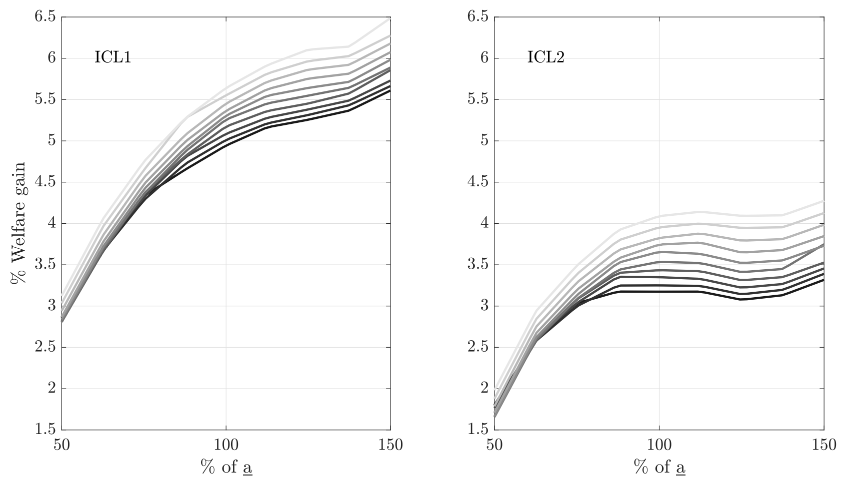

Fig. 35: CEG in ICL1 and ICL2. Darker colors denote larger $\underline{b}$ borrowing limits (from 50% to 250%).

7.8 Age of enrolment

The welfare gains reported in Sections 3 and 4 are likely conservative. In a perpetual youth setting, agents can choose to enrol in university at any point in time.[65] Fig. 36 shows that while most agents enrol in university early in life, a significant proportion delay their education. For instance, in the baseline (NICL) steady state, around 80% of students enrol by age 29, aligning well with data from the United States in 2019, where 84% of undergraduate university enrolment was composed of individuals aged 29 or younger. The perpetual youth framework is flexible in

[65]In contrast, life-cycle models often include the assumption that education can only occur at the beginning of life. An exception is Johnson (2013).

that it can capture agents delaying investment in education as they build up enough wealth.[66] However, the model underpredicts the amount of students that engage in higher education shortly after high school. It also overpredicts the share of students that enrol in later stages of life.

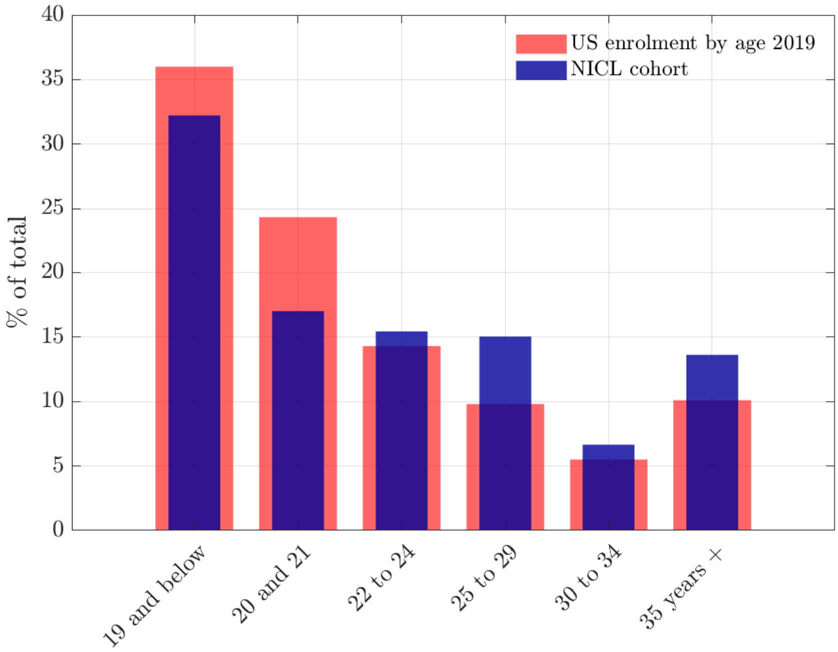

Fig. 36: Undergraduate age of enrolment at degree granting institutions in the U.S. vs age of enrolment in a simulated cohort of newborns in NICL. Source: U.S. Department of Education, National Center for Education Statistics.

In a life-cycle environment where agents can choose to study at any time, rising opportunity costs, declining educational ability, and increasing mortality risk reduce the feasibility of delaying education to save for university. In that setting, agents will be less likely to delay and save up for college. So we should expect to see less investment in education and higher inequality under the same calibration. Consequently, higher education systems that facilitate earlier enrolment for individuals who might otherwise forgo education are likely to generate even greater welfare gains in a life-cycle framework.

Turning to Europe and the OECD, we can see similar patterns of enrolment by age as those observed in the United States. Fig. 37 shows a breakdown of enrolment into higher education by age in the UK. In the 2022/2023 academic year in the UK, 32% of students enrolling for a first degree at university were over the age of 21. Fig. 38 depicts the average age of enrolment for a first degree in the OECD. We can see that the average age of enrolment varies subtantially, ranging from 18 to 25. In summary, while the majority of individuals pursue tertiary education shortly after leaving high school, a significant proportion delay this investment for several years.

Given the enrolment patterns, it is plausible that the perpetual youth framework provides conservative welfare estimates in European contexts as well, particularly in countries where financial constraints incentivise delaying enrolment in tertiary education. Increasing the generosity of higher education funding could encourage individuals to invest in education earlier, rather than delaying due to financial concerns, thereby amplifying the welfare gains observed in the paper.

[66]Financial concerns are listed as one of the primary reasons why there is delayed college enrty (see Lin and Liu (2019) and Demos and Young Invincibles (2011) for the US and Million Plus and OFA (2018) for the UK).

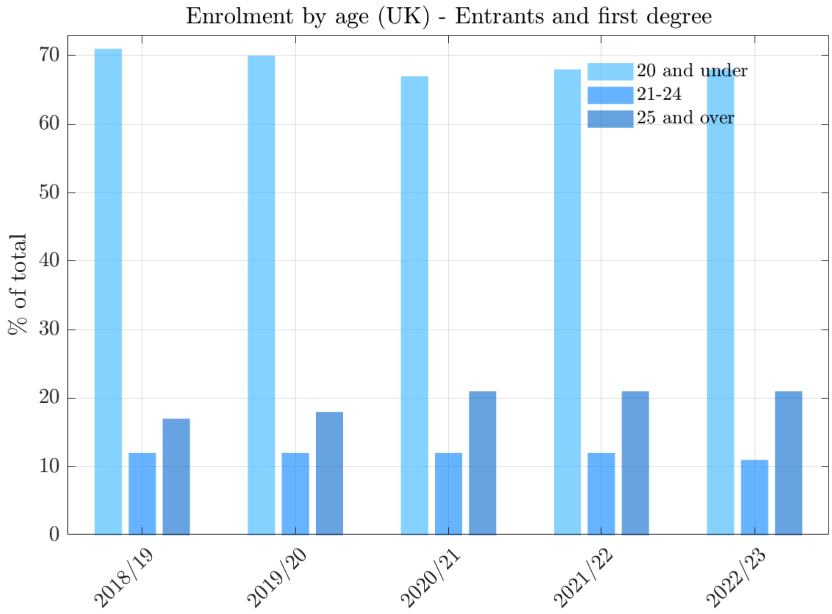

Fig. 37: Age of enrolment of first entrants in first degree in the UK. Source: HESA.

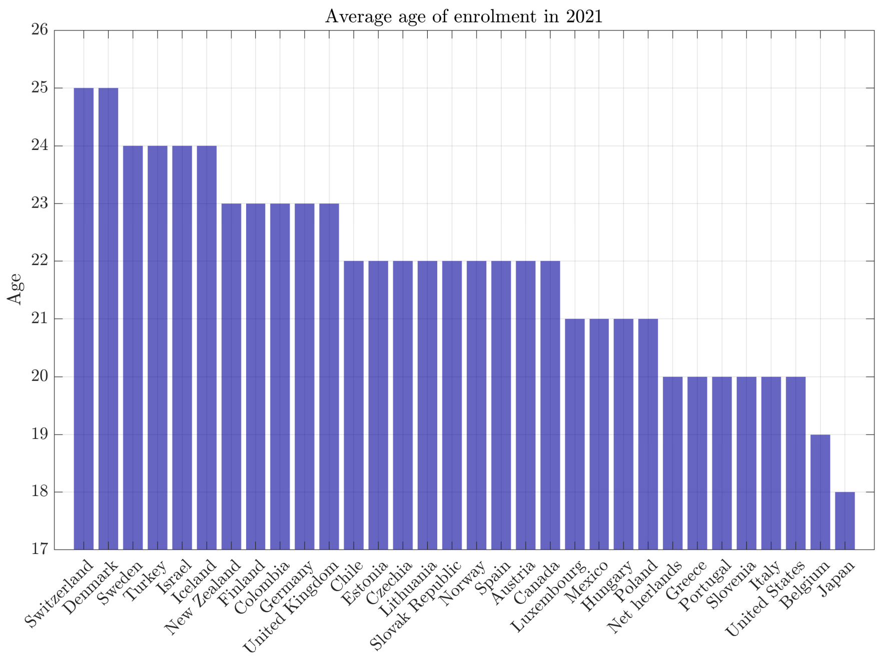

Fig. 38: Average age of first-time entrants to higher education in 2021. Source: OECD.

References

Abbott, B., G. Gallipoli, C. Meghir, and G. L. Violante (2019): "Education policy and intergenerational transfers in equilibrium," *Journal of Political Economy*, 127, 2569–2624.

Achdou, Y., J. Han, J.-M. Lasry, P.-L. Lions, and B. Moll (2022): "Income and wealth distribution in macroeconomics: A continuous-time approach," *The review of economic studies*, 89, 45–86.

Aiyagari, S. R. (1994): "Uninsured idiosyncratic risk and aggregate saving," *The Quarterly Journal of Economics*, 109, 659–684.

Akyol, A. and K. Athreya (2005): "Risky higher education and subsidies," *Journal of Economic Dynamics and Control*, 29, 979–1023.

Angelopoulos, K., S. Lazarakis, and J. R. Malley (2017): "Wealth inequality and externalities from ex ante skill heterogeneity," .

Arrazola, M., J. de Hevia, M. Risueño, J. F. Sanz, et al. (2005): "A proposal to estimate human capital depreciation: Some evidence for Spain," *Hacienda Publica Espanola–Revista de Economia Publica*, 172, 9–22.

Athreya, K., F. Ionescu, U. Neelakantan, and I. Vidangos (2019): "Who values access to college?" Finance and Economics Discussion Series 2019-015, Washington: Board of Governors of the Federal Reserve System.

Barr, N. and I. Crawford (2000): "Student loans: A hungarian proposal," Discussion paper.

Belfield, C., J. Britton, F. Buscha, L. Dearden, M. Dickson, L. Van der Erve, A. Sibieta, A. Vignoles, I. Walker, and Y. Zhu (2018a): "The impact of undergraduate degrees on early-career earnings," Institute for Fiscal Studies and Department for Education.

Belfield, C., J. Britton, F. Buscha, L. Dearden, M. Dickson, L. Van Der Erve, L. Sibieta, A. Vignoles, I. Walker, and Y. Zhu (2018b): "The relative labour market returns to different degrees: Research report: June 2018," Institute for Fiscal Studies and Department for Education.

Ben-Porath, Y. (1967): "The production of human capital and the life cycle of earnings," *Journal of Political Economy*, 75, 352–365.

Bénabou, R. (2002): "Tax and education policy in a heterogeneous-agent economy: What levels of redistribution maximize growth and efficiency?" *Econometrica*, 70, 481–517.

Boppart, T. and P. Krusell (2020): "Labor supply in the past, present, and future: a balanced-growth perspective," *Journal of Political Economy*, 128, 118–157.

Bovenberg, A. L. and B. Jacobs (2005): "Redistribution and education subsidies are Siamese twins," *Journal of Public Economics*, 89.

Britton, J., L. Dearden, L. van der Erve, and B. Waltmann (2020): "The impact of undergraduate degrees on lifetime earnings: Research report, February 2020," Institute for Fiscal Studies and Department for Education.

Cagetti, M. and M. De Nardi (2006): "Entrepreneurship, frictions, and wealth," *Journal of political Economy*, 114, 835–870.

Cai, Z. and J. Heathcote (2018): "College tuition and income inequality," CEPR Discussion Paper No. DP13101, CEPR.

Card, D. and T. Lemieux (2001): "Can falling supply explain the rising return to college for younger men? A cohort-based analysis," *The Quarterly Journal of Economics*, 116, 705–746.

Carnevale, A. P., N. Smith, M. Melton, E. Price, et al. (2015): "Learning while earning: The new normal." *Georgetown University Center on Education and the Workforce.*

Caucutt, E. M. and L. Lochner (2020): "Early and late human capital investments, borrowing constraints, and the family," *Journal of Political Economy*, 128, 1065–1147.

College Board (2018): "Trends in college pricing," *Trends in Higher Education Series.*

Davies, J. B., S. Sandström, A. Shorrocks, and E. N. Wolff (2011): "The level and distribution of global household wealth," *The Economic Journal*, 121, 223–254.

Dávila, J., J. Hong, P. Krusell, and J. V. Ríos Rull (2012): "Constrained efficiency in the neoclassical growth model with uninsurable idiosyncratic shocks," *Econometrica*, 80, 2431–2467.

De Nardi, M. and G. Fella (2017): "Saving and wealth inequality," *Review of Economic Dynamics*, 26, 280–300.

Dearden, L., E. Fitzsimons, A. Goodman, and G. Kaplan (2008): "Higher education funding reforms in England: The distributional effects and the shifting balance of costs," *The Economic Journal*, 118, F100–F125.

Demos and Young Invincibles (2011): "The state of young America: Economic barriers to the American dream," .

Floden, M. (2001): "The effectiveness of government debt and transfers as insurance," *Journal of Monetary Economics*, 48, 81–108.

García-Peñalosa, C. and K. Wälde (2000): "Efficiency and equity effects of subsidies to higher education," *Oxford Economic Papers*, 52, 702–722.

Hanushek, E. A., C. K. Y. Leung, and K. Yilmaz (2003): "Redistribution through education and other transfer mechanisms," *Journal of Monetary Economics*, 50, 1719–1750.

——— (2014): "Borrowing constraints, college aid, and intergenerational mobility," *Journal of Human Capital*, 8, 1–41.

Heijdra, B. J., F. Kindermann, and L. S. Reijnders (2017): "Life in shackles? The quantitative implications of reforming the educational financing system," *Review of Economic Dynamics*, 25, 37–57.

Herrington, C. M. (2015): "Public education financing, earnings inequality, and intergenerational mobility," *Review of Economic Dynamics*, 18, 822–842.

Holter, H. A. (2015): "Accounting for cross-country differences in intergenerational earnings persistence: The impact of taxation and public education expenditure," *Quantitative Economics*, 6, 385–428.

Huang, J. and J.-S. Pang (1998): "Option pricing and linear complementarity," *Journal of Computational Finance*, 2, 30–61.

Hugonnier, J., F. Pelgrin, and P. St-Amour (2019): "Self-inflicted unemployment scarring and stigma," Discussion paper, Netspar.

Ionescu, F. (2009): "The federal student loan program: Quantitative implications for college enrollment and default rates," *Review of Economic Dynamics*, 12, 205–231.

Ionescu, F. and N. Simpson (2016): "Default risk and private student loans: Implications for higher education policies," *Journal of Economic Dynamics and Control*, 64, 119–147.

James, J. (2012): "The college wage premium," Economic Commentary 2012-10, Federal Reserve Bank of Cleveland.

Johnson, M. T. (2013): "Borrowing constraints, college enrollment, and delayed entry," *Journal of Labor Economics*, 31, 669–725.

Kirby, P. (2016): "Degrees of debt: Funding and finance for undergraduates in anglophone countries." Tech. rep., Sutton Trust.

Krueger, D. and A. Ludwig (2016): "On the optimal provision of social insurance: Progressive taxation versus education subsidies in general equilibrium," *Journal of Monetary Economics*, 77, 72–98.

Light, A. and W. Strayer (2000): "Determinants of college completion: School quality or student ability?" *Journal of Human Resources*, 299–332.

Lin, Y. and V. Y. T. Liu (2019): "Timing matters: How delaying college enrollment affects earnings trajectories," Tech. Rep. CCRC Working Paper No. 105, CCRC, Columbia University, New York, NY.

Lise, J., C. Meghir, and J.-M. Robin (2016): "Matching, sorting and wages," *Review of Economic Dynamics*, 19, 63–87.

Looney, A. and C. Yannelis (2019): "How useful are default rates? Borrowers with large balances and student loan repayment," *Economics of Education Review*, 71, 135–145.

Luo, M. and S. Mongey (2019): "Assets and Job Choice: Student Debt, Wages and Amenities," Discussion paper.

Manuelli, R., A. Seshadri, and Y. Shin (2012): "Lifetime labor supply and human capital investment," Discussion paper.

Million Plus and OFA (2018): "Forgotten learners: building a system that works for mature students," .

Moll, B. (2016): "Exercising an Option: Numerical Solution," Technical note.

NCES (2018): *Integrated Postsecondary Education Data System (IPEDS)*, U.S. Department of Education, National Center for Education Statistics.

Nuño, G. and B. Moll (2018): "Social optima in economies with heterogeneous agents," *Review of Economic Dynamics*, 28, 150–180.

Obiols-Homs, F. (2011): "On borrowing limits and welfare," *Review of Economic Dynamics*, 14, 279–294.

Sonnet, A. (2010): *Off to a good start? Jobs for youth*, OECD.

Staklis, S. and A. Bentz (2016): "Employment and enrollment status of baccalaureate degree recipients 1 year after graduation: 1994, 2001, and 2009. Web Tables. NCES 2017-407." *National Center for Education Statistics.*

Valletta, R. G. (2018): "Recent flattening in the higher education wage premium: Polarization, skill downgrading, or both?" in *Education, skills, and technical change: Implications for future US GDP growth*, University of Chicago Press, 313–342.

Vandeplas, A. (2020): "Education, income, and inequality in the European Union," in *Europe's Income, Wealth, Consumption, and Inequality*, ed. by G. Fischer and R. Strauss, Oxford University Press, 300.

Waltmann, B. (2022): "Student loans reform is a leap into the unknown," *Institute for Fiscal Studies.*