Life in shackles?*
The quantitative implications of reforming the educational financing system

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Abstract: We conduct a quantitative analysis of educational financing systems in a stochastic overlapping generations model in which human capital can be enhanced through both formal schooling and learning-by-doing. The model is calibrated to the US economy, including a stylized version of its mortgage loan system. We find that moving to a degree tax system, whereby transfers to students are financed with a degree-specific tax on labour income, generates an aggregate welfare gain. It improves risk-sharing among the educated workforce and incentivizes students to stay in tertiary education longer. These positive effects overturn the negative impact from labour supply distortions. Similar positive but less pronounced results are obtained under a graduate tax system in which the educational tax is constant across all workers with a tertiary degree. Financing transfers to students through comprehensive labour taxes, however, results in an aggregate welfare loss as it leads to regressive redistribution from the uneducated to the educated. The three reform options generate a considerable amount of transitional dynamics, so that welfare gains and losses are distributed unevenly across generations.

Keywords: Education, human capital, study loans, uninsured labour market risk, incomplete markets, overlapping generations.

JEL Codes: E10, E24, D91, I22, J24.

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1 Introduction

> "...student loan systems [...] are often badly designed for an extended period of high unemployment. In contrast to the housing crash, the risk from student debt is not of a sudden explosion in losses but of a gradual financial suffocation. The pressure needs to be eased."
>
> *The Economist* (October 29th, 2011)

Obtaining a college degree typically requires a large investment of time and money. In order to facilitate access to higher education most governments have instituted an educational loan system of one kind or another. For example, in the United States there are four major federal sources of loans – subsidized and unsubsidized Stafford loans, the PLUS program, and the Perkins loans – as well as private sector loans (Avery and Turner, 2012). In the last two decades, study loans have become an increasingly important source of funds to finance a college education in the US. Loan take up rates have more than doubled and the average size has even tripled (Kuhn and Ríos-Rull, 2015). This is potentially worrisome, as the return to education is quite risky. Apart from a certain amount of input risk, meaning that upon entering a study program one cannot be sure to actually successfully complete a degree, there is also a considerable amount of heterogeneity in earnings of successful college graduates, the so-called output risk. To deal with these risks, researchers have argued that income-based payments should be preferred over standard mortgage loans, as they at least partly insure individuals against the risk of a low return to a college education. With the upcoming elections in the United States, candidates presented several plans on "how to fix the country's broken system of university finance" (*The Economist*, August 22nd, 2015). While Hillary Clinton wants repayments of college loans to be capped at 10 percent of income, Marco Rubio – inspired by Milton Friedman's work – favours an equity financing scheme. Yet, Milton Friedman himself once famously compared income-based financing of education to partial slavery. But should this not be preferred to the gradual suffocation of debt?

In the present paper we want to assess the effects of reforming the educational financing system of the United States in a quantitative macroeconomic model with overlapping generations. We augment an otherwise standard version of this model to include important features of the human capital accumulation process. Human capital in our model can be accumulated via two channels: through formal education and learning on the job. Having completed high school, each individual chooses the optimal years of tertiary education given his or her talent for learning in school. In order to finance both tuition and consumption expenditure during the time of study, students receive transfers from the government. Once formal education is over, the individual joins the labour force and learns about his or her ability to accumulate human capital via the learning-by-doing mechanism. Following the pioneering work by Bewley (1977), Aiyagari (1994) and Huggett (1993, 1997), we assume that individuals experience uninsurable idiosyncratic labour productivity shocks, including the possibility of (temporary) unemployment. This implies that labour income is stochastic and that the type of educational financing system in place will influence the kind of financial distress that someone with a bad run in the labour market will experience.

We calibrate our model to the US economy, including a stylized version of its Mortgage Loan (ML) system. In this system the transfers that a student has received during the education phase constitute the study debt that he/she has to redeem in fixed installments after graduation. We then consider three possible reforms: either a Comprehensive Tax (CT) system, a Graduate Tax (GT) system, or a Degree Tax (DT) system. The three alternative systems have in common that transfers to students are financed by means of taxes but they differ in the specification of the tax base. With a comprehensive tax all workers face an additional tax on their labour earnings, while a graduate tax is only levied on educated individuals. Finally, a degree tax differentiates by the highest degree earned therefore taking into account that individuals with more education incur larger costs. For each reform scenario we compute both the transitional and long-run effects of the policy change on micro- and macroeconomic outcomes and calculate welfare changes for current and future generations.

Our main findings are as follows. First, the reform from ML to CT produces a strong increase in long-run average educational attainment. Intuitively, since education expenditure under this system is financed from general tax revenue, each individual has to pay a share of the total cost of education, regardless of which degree he/she actually pursues. This regressive redistribution substantially increases the return to a college education. In a reform from ML to GT the proportion of uneducated workers stays roughly constant. However, conditional on going to college, the average number of years of schooling goes up following the same logic as above. Finally, a degree tax strives to minimize the extent of redistribution between individuals of different education levels while at the same time allowing for risk sharing among those who pursued the same study path. Hence, a reform from ML to DT produces a reduction in the proportion of unskilled in the economy and moderate increases in all degree categories.

Second, all three reforms produce significant long-run effects on the macroeconomy and on ex ante welfare. As the tax-based educational financing systems are organized on a pay-as-you-go basis, in all reforms the capital stock as well as the capital intensity rise causing a reduction in the interest rate and an increase in the wage rate. Output increases by, respectively, 1.03% and 0.79% under the reforms CT and GT but stays more or less constant in the reform from ML to DT. Long-run welfare increases under all reforms, with the effect being most pronounced under GT and DT.

Third, in addition to these long-run effects, there exists a considerable amount of transitional dynamics in the model and it takes roughly half a century before the economy is close to its new steady state. The slow but realistic transition speed results from the fact that there are two slow-moving stocks in the model, namely physical and human capital (cf. Mankiw *et* *al.*, 1992). We find a considerable heterogeneity in welfare effects across different generations along the transition. For generations that are already economically active at the time of the reform welfare invariably falls. This result follows readily from the fact that they are – in a sense – paying the same bill twice. They must continue to pay off any existing study debt, but are also hit by a higher labour-income tax. Students are hurt as well, but to a lesser extent the younger they are (and thus the lower is the already incurred study debt). Interestingly, under the GT and DT reform all future generations gain from the policy change. In contrast, in the case of CT only generations born more than two decades after the reform experience an increase in ex ante welfare.

Fourth, when aggregating welfare effects across all affected generations, it turns out that for GT and DT the gains of post-shock cohorts are large enough to compensate the losers from the policy reform so that aggregate welfare increases. For CT, on the other hand, the long-run welfare gains stem solely from intergenerational redistribution so that aggregate welfare falls under this scenario.

Last, we perform a decomposition analysis of the aggregate welfare effects to investigate the quantitative importance of the different mechanisms at work in the model. In all cases the introduction of a tax discourages labour supply so that there is a negative work incentive effect. Nevertheless, the positive effect of improved risk-sharing opportunities, increased educational attainment and changes in factor prices overcompensates the loss from labor supply distortions and result in an overall welfare gain especially for the DT system. The difference in aggregate welfare effects between DT and the other two systems can be almost exclusively attributed to the negative impact of regressive redistribution from the lower to the higher skilled. While under GT this effect is relatively mild, it leads to substantial aggregate welfare losses under the CT system.

1.1 Education financing in theory and practice

If borrowers are risk averse and lender risk neutral then the first-best credit contract to finance investment in education provides full insurance against fluctuations in income (see for example Lochner and Monge-Naranjo, 2015). This strong result changes somewhat once allowance is made for incentive problems such as adverse selection and moral hazard. Nevertheless, the optimal contract should still provide as much insurance as possible by making repayments contingent on income.

One way to achieve this is by moving from debt financing to equity financing. In a masterful chapter in *Capitalism and Freedom* (1962), Milton Friedman strongly favours such an equity-based system for investments in education. It would be advantageous if it were possible "...to 'buy' a share in an individual's earning prospects; to advance him the funds needed to finance his training on condition that he agree to pay the lender a specified fraction of his future earnings. In this way, a lender would get back more than his initial investment from relatively successful individuals, which would compensate for the failure to recoup his original investment from the unsuccessful." (p. 103). He notes that the government is able to institute such a system of equity investment in human beings at a much lower cost than the private sector could because it already possesses the power to tax individuals.

The existing programs that come closest to equity financing are the income-contingent loan systems in Australia, New Zealand and the United Kingdom. Although different in the details (see Lochner and Monge-Naranjo (2015) for an excellent overview), in each case the amount that the borrower repays at a certain moment in time depends on the income earned and is collected via taxes. In addition, payments only need to be made in case income exceeds a given threshold. The recently introduced Pay-As-You-Earn system in the United States and the Repayment Assistance Plan in Canada are similar but payments are not collected via taxes and the systems are only available to individuals who experience financial hardship. In all cases, contributions stop once the individual has redeemed his or her own debt, which may be soon for lucky individuals but can take a long time for others. Note that this feature limits the degree of risk sharing among college graduates in these programs.

The tax-based reforms of educational financing that we study in this paper are clearly more stylized than the real-world counterparts. The comprehensive tax system, under which transfers to students are financed out of general tax revenue, comes quite close to the practice in some European countries like for example Germany, in which all the direct cost of education are financed out of general tax money and many students on top receive highly subsidized loans (with repayments rates of only 50% or less) to finance their cost of living. The graduate tax and degree tax are equity financing systems in the sense that students "sell" a fraction of their future income to the government upon entering higher education in reward for receiving money during the time of study. The difference between GT and DT is that under the latter, the share of income "sold" to the government increases with the number of years spent in higher education, reflecting the fact that the amount of transfers received is also larger.

One could imagine similar systems of equity financing to be implemented on a private basis instead of being administered by the government. This would, however, immediately give rise to a couple of other issues. If private investors could invest in a student's "equity", they would potentially want to skim off the cream of students by screening their ability, which can be a very costly process. At the same time they might demand high risk premia for all other individuals. In such a system high ability students might want to signal their abilities in order to attract an equity investment with favorable conditions. Analyzing market equilibria in such an environment, however, goes way beyond the scope of this paper.

1.2 Relation to the existing literature

Our paper relates to a growing literature that is concerned with the financing of higher education. There are many theoretical contributions, prominent examples of which include

García-Peñaloza and Wälde (2000), Jacobs and van Wijnbergen (2007), Cigno and Luporini (2009), DelRey and Racionero (2010), Lochner and Monge-Naranjo (2011), and Eckwert and Zilcha (2012). These papers are invariably highly stylized in their description of economic decision making and are thus unsuitable for the quantitative analysis of educational financing systems. In recent years, however, a literature had emerged which uses the techniques of modern stochastic macroeconomics – in particular the incomplete markets model – to study education subsidies. Examples include Akyol and Athreya (2005), Ionescu (2009), Krueger and Ludwig (2013), and Abbott *et al.* (2013). Of these, the paper by Abbott *et al.* (2013) is most closely related to ours. Although both papers use a common quantitative methodology, their focus is quite distinct. For example, Abbott *et al.* (2013) include a detailed description of how individuals decide about education and what exactly their resources are during the schooling period, i.e. both study loans and borrowing constraints are modeled in detail. In addition, they include in vivo transfers from parents to offspring and assume that there exists an intergenerational transmission of ability. In their computational implementation they restrict attention to steady-state comparisons. In contrast, we focus mainly on the design of repayment schemes, keeping resources of individuals at the beginning of life (and during the time of study) constant. By adopting a less detailed description of the schooling phase we are able to compute the transitional dynamic effects of policy reforms. In doing so we can demonstrate the rather uneven distribution of costs and benefits over the different generations. We thus show that the actual implementation of policy reforms that improve long-run welfare may meet with a lot of political opposition in the short run.

The remainder of the paper is structured as follows. In Section 2 we formulate our baseline model. Section 3 discusses the calibration and visualizes some key features of this model. Section 4 presents the quantitative results from our three reform scenarios. Section 5 summarizes and concludes. Technical details can be found in Heijdra *et al.* (2014).

2 Model

In this section we develop a stochastic general equilibrium model of a closed economy. We discuss firms in Section 2.1, followed by a description of individual behaviour in Section 2.2. Then we outline the details of the different educational financing schemes (Section 2.3) and the government budget (Section 2.4), concluding with a definition of market clearing in Section 2.5.

2.1 Firms

Perfectly competitive firms combine physical capital and efficiency units of labour in order to produce homogeneous output, the price of which serves as the numeraire. We abstract from aggregate uncertainty and capital adjustment costs so the representative firm essentially makes a sequence of static decisions regarding output supply and factor demands.

The production function is of the Cobb-Douglas type:

$$Y_t = \Phi K_t^{\phi} [Z_t N_t]^{1-\phi}, \quad 0 < \phi < 1, \quad \Phi > 0, \tag{1}$$

where t is the time index, Y_t is output, K_t is the stock of physical capital, and N_t is the amount of effective labour employed in production. The parameter ϕ captures the income share of capital while the index of labour-augmenting technological change, Z_t, grows at an exogenous rate $n^z > 0$. The firm's stock of physical capital evolves according to $K_{t+1} = (1 - \delta^k)K_t + I_t$, where I_t is gross investment and δ^k is the (constant) rate of depreciation. The real profit flow at time t is given by $Y_t - w_t N_t - (r_t + \delta^k)K_t$, where r_t is the interest rate and w_t is the rental rate on effective labour. The profit-maximizing mix of inputs gives rise to the following marginal productivity conditions:

$$r_t + \delta^k = \phi\Phi \left[\frac{K_t}{Z_t N_t}\right]^{\phi-1}, \qquad \frac{w_t}{Z_t} = (1-\phi)\Phi \left[\frac{K_t}{Z_t N_t}\right]^{\phi}. \tag{2}$$

With these factor demands, profit is zero because of the linear homogeneity of the technology and perfect competition.

2.2 Individuals

2.2.1 Stochastic environment over the life cycle

Each individual lives for $\bar{U} + 1$ years with certainty, such that age $u \in \{0, 1, \ldots, \bar{U}\}$. The individual graduates from high school at the age of majority M and starts making economic decisions from that age onward. The sequence of events in a person's life is summarized in Figure 1.

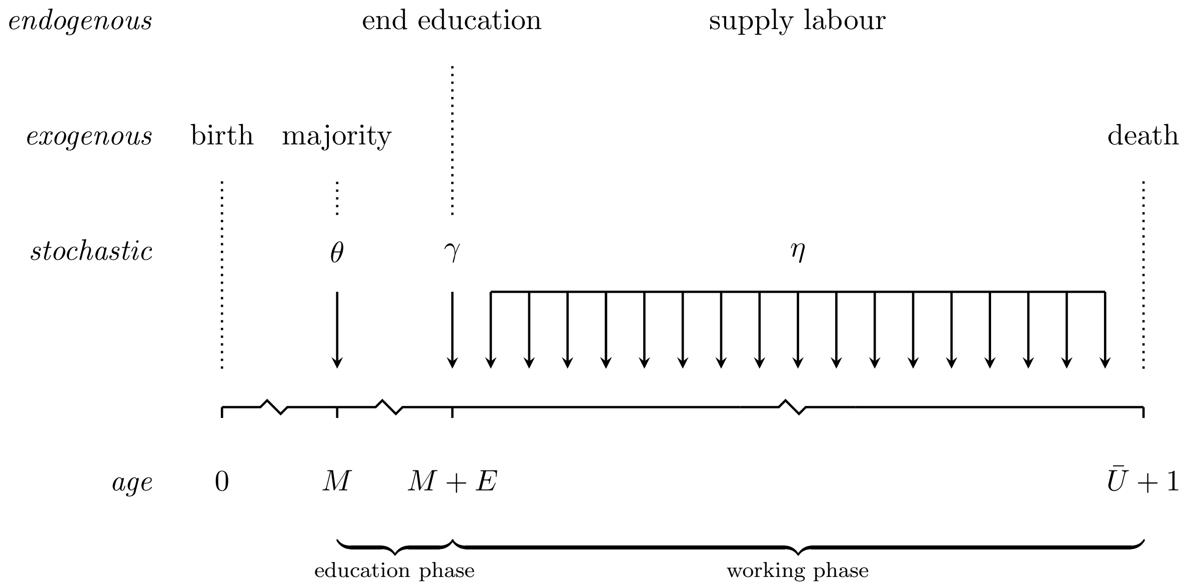
At different moments in the life cycle nature reveals two important learning characteristics. First, at the age of majority M the innate talent for (tertiary) education, θ, is drawn from a distribution with support $[0, 1]$. Educational talent affects the returns to education experienced by the individual. In particular, the stock of human capital at labour market entry given talent for education θ and years of education E is given by $\Gamma(\theta, E)$:

$$\Gamma(\theta, E) = 1 + \xi_1 \theta E - \xi_2 [1 - \theta] E^2, \quad \xi_1 > 0, \quad \xi_2 > 0. \tag{3}$$

Note that someone who chooses no education at all ($E = 0$) enters the labour force with one unit of human capital.

Second, upon completion of the optimally chosen schooling period, nature reveals the individuals's ability to learn on the job which we denote by γ. We assume that the learning-

Figure 1: The individual's life cycle

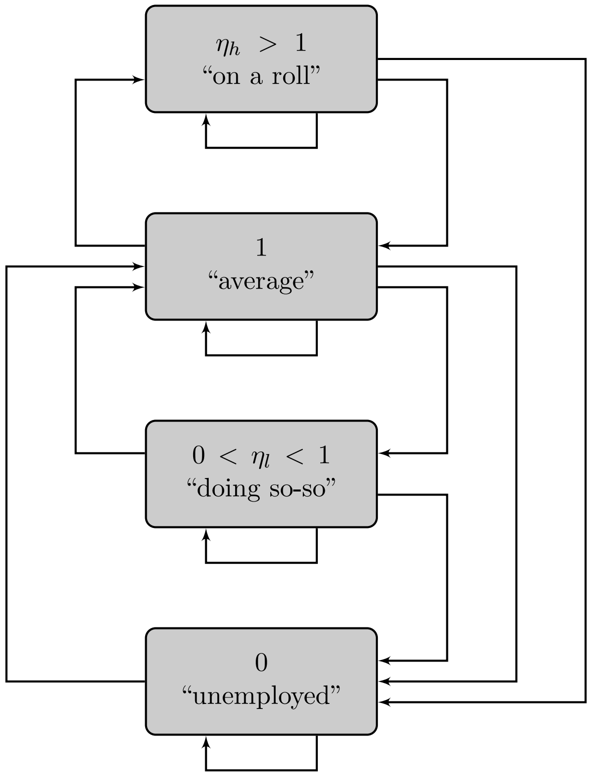


by-doing (LBD) parameter γ can take on two values, $\gamma \in \{\gamma_l, \gamma_h\}$, with $0 < \gamma_l < \gamma_h < 1$. We assume that γ is positively correlated with θ so that an individual who is very talented at school is also likely to learn quickly on the job.

Third, there is a draw for the idiosyncratic labour productivity shock η in every period. For computational reasons we assume that the process for η takes the form of a stationary Markov chain with four states $\eta \in \{0, \eta_l, 1, \eta_h\}$ satisfying $0 < \eta_l < 1 < \eta_h$. The transition probabilities between states depend on the individual's schooling level. We incorporate some real-world features into this simple Markov scheme which we find relevant for workers who may have a sizeable study debt. In particular, the notion of (temporary) unemployment is captured by setting the lowest realization for η equal to zero. In the numerical implementation the elements of the Markov transition matrix are chosen in such a way that the process replicates key characteristics of wage income data of employed individuals in the US (such as persistence and variability – see below). The first draw of η upon labour market entry is equal to unity, which we call average productivity. We impose a lot of additional structure on the Markov process in that (a) any productive worker can become unemployed, (b) barring moves to unemployment a productive worker can only move up or down by a single state level, and (c) a previously "unemployed" individual moves to the average productivity level or stays unemployed. This is summarized in Figure 2.

Individuals are assumed to be fully aware of the stochastic environment they live in and to formulate optimal life-cycle plans which maximize their utility subject to the constraints they face. It is most convenient to describe an individual's optimization problem backwards, i.e. starting with the employment phase and ending with the education phase.

Figure 2: Markov process for labour productivity η



2.2.2 Optimal decisions of a worker

Consider a worker who is of age u, has enjoyed E years of education, and features a LBD parameter γ. At the start of year t this individual owns stocks of financial assets a and human capital h and has a labour productivity level η. The individual chooses current consumption c and labour supply l as well as next-periods financial assets a^+ and human capital h^+ in order to maximize remaining lifetime utility. The optimization problem is characterized by the Bellman equation:

$$V_{u,t}(E,\gamma,a,h,\eta) = \max_{c,l,a^+,h^+} \Bigg\{ \left[c^{\varepsilon}(1-l)^{1-\varepsilon}\right]^{1-1/\sigma} + \beta\left[\mathbb{E}_{\eta^+|\eta,E}\left[V_{u+1,t+1}(E,\gamma,a^+,h^+,\eta^+)^{1-\zeta}\right]\right]^{\frac{1-1/\sigma}{1-\zeta}} \Bigg\}^{\frac{1}{1-1/\sigma}} \tag{4}$$

in combination with the laws of motion of the state variables and the constraints on the choice variables:

$$a^+ = [1+(1-\tau_t^r)r_t]a + (1-\tau_t^w)w_t\eta hl - (1+\tau_t^c)c + \nu_{u,t}\mathbb{1}_{\{\eta=0\}} - \Upsilon_{u,t}(E, w_t\eta hl) \tag{5a}$$

$$h^+ = (1-\delta_u^h)[1+\gamma l^\alpha]h \tag{5b}$$

$$0 \le l \le 1, \qquad c \ge 0, \qquad a^+ \ge 0, \tag{5c}$$

where β is the time discount factor ($0 < \beta < 1$), τ_t^r, τ_t^w, and τ_t^c are tax rates on, respectively, interest income, wage earnings, and consumption, $\nu_{u,t}$ is the unemployment benefit, $\mathbb{1}_{\{\eta=0\}}$ is an indicator function which equals unity if $\eta = 0$ and zero otherwise, and $\Upsilon_{u,t}(E, W)$ is the payment to the educational financing system during period t for someone of age u with education E and gross wage income W.[1]

Several things are worth noting. First, the preference structure satisfies the King-Plosser-Rebelo conditions (see King *et al.*, 2002) so that – in the presence of ongoing labour productivity growth – a stationary decision problem is obtained by scaling the individual's consumption and financial assets (as well as wages, unemployment benefits, and repayments) by an index of productivity. See Heijdra *et al.* (2014) for details.

Second, preferences are of the recursive form suggested by Epstein and Zin (1991) which allows us to disentangle the individual's attitudes towards risk and intertemporal consumption smoothing. Using the terminology of Backus *et al.* (2004, p. 341), the time-aggregator and certainty-equivalent functions are both of the CES type. In this formulation, σ parameterizes the *inter*temporal substitution elasticity ($\sigma > 0$) whilst ζ captures the degree of relative risk aversion ($\zeta \ge 1$). The instantaneous felicity function is a Cobb-Douglas aggregate of consumption and leisure (with $0 < \varepsilon < 1$). This implies a unitary *intra*temporal substitution elasticity between consumption and leisure.

Third, the expectation $\mathbb{E}_{\eta^+|\eta,E}$ is with respect to next period's labour productivity η^+ and conditional on information about current productivity η and the education level E. Fourth, since γ is revealed when individuals enter the labour force and E is predetermined both are constants during the working phase. Finally, the value function depends on t because factor prices do. In addition it depends on the individual's age u because this determines the remaining length of life.

Expression (5a) states that the change in financial assets is equal to after tax income net of spending on consumption and payments to the educational financing system. Expression (5b) shows that the accumulation of human capital during the working phase depends on two distinct mechanisms. The *learning-by-doing effect* (LBD) is captured by the term γl^α. Conditional on the individual's LBD coefficient γ, more experience is gained the more he/she works (though at a diminishing rate as $0 < \alpha < 1$). The *economic ageing effect* is captured by the term $1 - \delta_u^h$ and results from the fact that the depreciation rate on human capital is taken to be increasing in age (as in Heijdra and Reijnders, 2012). In particular, for $M \le u \le \bar{U}$ we

[1] We include a highly stylized unemployment benefit system in which the benefit is the same for everyone and thus does not depend on the last-earned wage.

postulate:

$$\delta_u^h = 1 - \delta_0 \left(\frac{\bar{U} - u}{\bar{U} - M} \right)^{\delta_1}, \quad 0 \leq \delta_1 \leq 1, \quad 0 < \delta_0 \leq 1. \tag{6}$$

Finally, the expressions in (5c) show that labour supply, consumption, and financial assets must be non-negative. We thus impose the restriction – conventional in the macroeconomic literature on idiosyncratic risk – that individuals are unable to borrow for other purposes than financing their education. An often stated rationale for this borrowing constraint is that there is a positive probability of receiving zero wage income in one or more periods (Low, 2005, p. 951) and human capital is inalienable (Friedman, 1962, p. 102).

2.2.3 Optimal decisions of a student

Individuals enter adulthood without any financial assets and with an endowment of one unit of human capital. Formal education takes place when the individual enters adulthood at age M and requires a fixed time input of $\bar{e}$ each period. Since the time endowment equals unity and working and studying are assumed to be mutually exclusive activities it follows that leisure during the educational phase is given by $1 - \bar{e}$. In the absence of labour income students finance their living expenses with government-provided transfers. The size of the transfer q_t and the tuition fee f_t are exogenously given and increase over time at the rate of economic growth, n^z. In addition we assume that consumption during the educational phase is also fixed, i.e. c_t is the remainder of the transfer after paying the tuition fee:[2]

$$c_t = \frac{q_t - f_t}{1 + \tau_t^c} \tag{7}$$

The education decision constitutes a discrete choice in the sense that there are only four possible levels on offer. That is, we postulate that either $E = 0$ (no tertiary education), $E = 2$ (associate degree), $E = 4$ (bachelor's degree) or $E = 6$ (master's degree). The stock of human capital at labour market entry for a person with educational talent θ and years of education E is given by $\Gamma(\theta, E)$ in (3). Note that the functional form of $\Gamma(\theta, E)$ implies that individuals with a higher ability level experience weaker diminishing returns to education. Furthermore, for the most talented individuals ($\theta = 1$) the relation between startup human capital and education level is linear:

$$\frac{\partial \Gamma(\theta, E)}{\partial E} = \xi_1 \theta - 2\xi_2 [1 - \theta] E, \qquad \frac{\partial^2 \Gamma(\theta, E)}{\partial E^2} = -2\xi_2 [1 - \theta] \leq 0. \tag{8}$$

These properties of $\Gamma(\theta, E)$ ensure that the optimal education choice is increasing in ability.

[2]Implicitly we assume that students would like to – but cannot – borrow more than q_t, i.e. students face a binding borrowing constraint.

In the absence of the diminishing-returns effect (with $\xi_2 = 0$) this may not be true because high-ability individuals also have a higher opportunity cost of time.

It is possible to choose the years of education only when not yet working. Consider a student with educational ability θ who is u years old at time t. We write this person's expected remaining life-time utility as follows:

$$S_{u,t}(\theta) = \max_{E \geq u-M} \left[\sum_{s=t}^{t-u+M+E-1} \beta^{s-t} \Big[\big(c_s\big)^{\varepsilon} \big(1-\bar{e}\big)^{1-\varepsilon} \Big]^{1-1/\sigma} + \beta^{M+E-u} \Big[\mathbb{E}_{\gamma|\theta} \Big[V_{M+E,t-u+M+E}\big(E, \gamma, 0, \Gamma(\theta, E), 1\big)^{1-\zeta} \Big] \Big]^{\frac{1-1/\sigma}{1-\zeta}} \right]^{\frac{1}{1-1/\sigma}} \quad (9)$$

Several things are worth noting. First, during the remaining period in school the student consumes fixed amounts of goods and leisure which gives rise to the first term on the right-hand side of (9). Second, at labour market entry the ability to learn on the job γ is revealed, financial assets are zero, marketable human capital is given by $\Gamma(\theta, E)$, and the individual's startup productivity is equal to $\eta = 1$. This explains the arguments entering the value function at the age of school leaving.

2.3 Educational financing system

It remains to specify the details of the system of educational financing that is in place at any point in time. In particular we must formulate the functional form for $\Upsilon_{u,t}(E, W)$ that features in the worker's budget constraint. We consider four stylized systems. The base case is the Mortgage Loan (ML) system in which individuals pay off their own study debt during their working career. In the three alternative systems transfers to students are financed by means of taxes but the systems differ in the specification of the tax base. With a Comprehensive Tax (CT) all workers face an additional tax on their labour earnings. In contrast, a Graduate Tax (GT) is only levied on educated individuals and a Degree Tax (DT) differentiates by the highest degree earned. We will discuss each of these options in more detail.

ML *Mortgage loans*

With mortgage loans the payment $\Upsilon_{u,t}(E, W)$ does not depend on wage income W. At each moment in time study debt $\Omega_{u,t}(E)$ depends on age u and years of education E only. Everyone starts adulthood without debt so that $\Omega_{M,t}(E) = 0$. During the education phase study debt increases as a result of interest payments on existing debt and exogenous loan inflows (the transfer received):

$$\Omega_{u+1,t+1}(E) = [1 + (1 - \tau_t^r) r_t] \Omega_{u,t}(E) + q_t, \quad \text{for } M < u + 1 \leq M + E.$$

Note that interest payments on study debt are tax deductible from asset income. However, since students do not earn any asset or wage income they effectively borrow at a subsidized rate of interest. During the working phase debt decreases because loan repayments exceed interest payments from then on:

$$\Omega_{u+1,t+1}(E) = [1 + (1 - \tau_t^r)r_t]\Omega_{u,t}(E) - \Upsilon_{u,t}(E, W) \quad \text{for } M + E < u + 1 \leq \bar{U}.$$

There are only redemption payments from age $\underline{u}(E)$ up to and including age $\overline{u}(E)$, the *redemption period*. If $\underline{u}(E) > M + E$ then there is a *grace period*. The size of the redemption payment $\Upsilon_{u,t}(E, W)$ is determined in such a way that – in the absence of unanticipated changes to the interest rate – the loan will be paid off at age $\overline{u}(E)+1$ if the payment remains constant during the remainder of the redemption period. Default does not happen because (a) there is a (small) social security system in place which covers zero-income periods and (b) rational individuals accumulate precautionary savings in order to avoid getting confronted with very low consumption levels in the future.

CT *Comprehensive tax*

When transfers to students are financed with a comprehensive labour tax the payment $\Upsilon_{u,t}(E, W)$ does not depend on education E directly:

$$\Upsilon_{u,t}(E, W) = \tau_t^e W,$$

However, more educated individuals tend to earn higher gross wages and therefore contribute more on average. Note that an individual can avoid making payments by not working. The educational tax rate τ_t^e is determined in such a way that in every period tax revenues exactly cover total transfers to current students.

GT *Graduate tax*

In a graduate tax system only educated individuals contribute to educational financing:

$$\Upsilon_{u,t}(E, W) = \tau_t^e \mathbb{1}_{\{E>0\}} W,$$

where $\mathbb{1}_{\{E>0\}}$ is an indicator function which equals unity provided E is positive and is zero otherwise. The tax rate is the same for each educated individual, regardless of the number of years spent in school, and is again determined on a pay-as-you-go basis.

DT *Degree tax*

A degree tax distinguishes between educated individuals and is conditional on the highest degree earned:

$$\Upsilon_{u,t}(E, W) = \tau_t^e(E) W.$$

where $\tau_t^e(E)$ is the educational tax rate for someone with E years of schooling. The tax rates are determined in such a way that workers with an associate degree only contribute to the transfers to students in their first two years of college, workers with a bachelor's degree also have to pay for the third and fourth year, while only those in possession of a master's degree cover transfers to master students.

2.4 Government budget

In addition to administering the educational financing system the government collects taxes on consumption, labour income and capital income to finance (intrinsically useless) public consumption G_t and unemployment benefits B_t. Total tax revenue, T_t, is equal to:

$$T_t \equiv \tau_t^c C_t + \tau_t^w w_t L_t + \tau_t^r r_t \Big[A_t - D_t \Big],$$

where C_t is total consumption, L_t effective labour supply, A_t financial assets and D_t study debt. We abstract from debt financing by the government so that the balanced budget requirement reduces to:

$$T_t = G_t + B_t.$$

2.5 Market clearing

The macroeconomic equilibrium is attained provided the following market clearing conditions are satisfied. First, the goods market equilibrium condition is given by:

$$Y_t = C_t + I_t + G_t + F_t,$$

where F_t is the total amount of tuition fees. Second, the capital market equilibrium condition states that the productive capital stock is equal to the net stock of assets owned by individuals:

$$K_t = A_t - D_t.$$

Finally, the labour market equilibrium condition requires equality between demand and supply of effective labour units:

$$N_t = L_t.$$

In the steady state of the model L_t and N_t increase at the population growth rate n^p and the wage rate w_t grows at the economic growth rate n^z. The remaining aggregate variables A_t, B_t, C_t, D_t, F_t, G_t, I_t, K_t, T_t and Y_t grow at rate $(1 + n^z)(1 + n^p) - 1$. By scaling these variables appropriately they will be constant in the long-run equilibrium, see Heijdra *et al.* (2014) for details.

3 Calibration

In this section we present and motivate the calibration of our model. In addition we visualize its main steady-state properties.

3.1 Distributions

We need to specify the distribution of the various stochastic model elements that have been discussed in Section 2.2.1. First, we assume that the talent for education θ follows a truncated normal distribution on $[0,1]$ with parameters μ_θ and σ_θ. This combines the convenience of a closed and bounded support with the flexibility of a bell-shaped curve. The second stochastic element is the ability to learn on the job γ which can only take two values. We specify the probability of a high draw conditional on θ as $\mathbb{P}\big(\gamma = \gamma_h|\theta\big) = 0.5 + \rho_{\gamma\theta}\big[F_\theta(\theta) - 0.5\big]$ where F_θ is the cumulative distribution function of θ. If $\rho_{\gamma\theta} > 0$ then there is a positive correlation between γ and θ. By setting $\gamma_l = \mu_\gamma - \sigma_\gamma$ and $\gamma_h = \mu_\gamma + \sigma_\gamma$ we ensure that the unconditional mean and variance are given by $\mathbb{E}[\gamma] = \mu_\gamma$ and $\mathrm{Var}(\gamma) = \sigma_\gamma^2$. Finally we have to specify the transition matrix for the Markov process that governs idiosyncratic labour productivity η. We assume that there is an education-specific probability to enter into 'unemployment' (i.e, $\eta = 0$) denoted by $\pi(E)$. There is a probability κ of returning to $\eta = 1$ in the next period and a probability $1 - \kappa$ of remaining unemployed for an additional year. Conditional on being employed (i.e., $\eta > 0$) labour productivity should mimic a log-AR(1) process with autocorrelation ρ_η and a stochastic innovation term with variance σ_ϵ^2. We impose some additional restrictions on transitions between states, see Section 2.2.1.

3.2 Parameter values

We calibrate the model to fit some key features of the US economy using a two-step procedure. First we assign to a subset of the parameters values that are taken directly from the data or the literature, see Table 1. İmrohoroğlu and Kitao (2009) provide an overview of estimates for the intertemporal substitution elasticity σ and we choose a value within the range they report. The coefficient of relative risk aversion is set in accordance with Cecchetti *et al.* (2000), who find that it is reasonable to have a value between 1 and 5.

Data from the World Bank for 2012 gives a population growth rate of 0.74% for the US. The maximum age is set equal to life expectancy at birth for the same year, rounded to the nearest integer. To obtain an estimate of the long run economic growth rate we collect data on GDP per capita from the Federal Reserve Economic Data of the St. Louis Federal Reserve

Table 1: Parameters taken from data or literature

Parameter		Value	Source
Preferences			
Intertemporal substitution elasticity	σ	0.500	İmrohoroğlu and Kitao (2009)
Coefficient of relative risk aversion	ζ	4.000	Cecchetti *et al.* (2000)
Demography			
Age of majority	M	18.000	
Population growth rate	n^p	0.007	WB for 2012
Maximum age	$\bar{U}$	79.000	WB for 2012
Technology			
Economic growth rate	n^z	0.020	FRED for 1970-2006
Wage uncertainty			
Autocorrelation of log productivity	ρ_η	0.821	Guvenen (2009)
Probability exiting unemployment	κ	0.990	
Probability entering unemployment	$\pi(0)$	0.048	March CPS for 2000-2006
Probability entering unemployment	$\pi(2)$	0.035	March CPS for 2000-2006
Probability entering unemployment	$\pi(4)$	0.027	March CPS for 2000-2006
Probability entering unemployment	$\pi(6)$	0.019	March CPS for 2000-2006
Study loans			
Annual loan to average income		0.238	NCES for 2012
Tuition fee as fraction of loan		0.400	
Length of grace period		4.000	
Length of redemption period		15.000	
Government			
Replacement rate unemployment		0.250	

Sources: CPS is the Current Population Survey. FRED is the Federal Reserve Economics Data of the St. Louis Federal Reserve Bank. NCES is the National Center for Education Statistics. WB is the World Bank.

Bank (measured in 2011 US dollars) and regress its log on a time variable. The resulting coefficient is 0.02 or 2% per year.

The growth rate of wages over the life cycle depends on an individual's ability to learn on the job and is therefore not the same for every person. We take an estimate for the autocorrelation of the labour productivity process ρ_η from Guvenen (2009), who allows for heterogeneity in income growth rates. In order to capture the fact that long-term unemployment (more than one year) is very uncommon we choose a value close to 1 for the recovery rate κ. We set the probability of entering unemployment $\pi(E)$ such that the unemployment rate by education group approximately matches the average over the years 2000 up to and including 2006 as calculated from the March Current Population Survey (CPS). It follows that education offers some insurance against being out of work as more educated individuals are less likely to become unemployed.

We include a simple system of unemployment protection. In the absence of such a social security scheme individuals would work 'too hard' and save 'too much' in the years immediately following graduation compared to the data. As they enter the labour market without any savings but do face the risk of unemployment they have an incentive to accumulate precautionary savings at a quick rate. In addition, if there is no redistribution towards the unemployed in the benchmark case then we are likely to overstate the welfare changes from reforming the educational financing system in such a way that it offers more insurance against low income periods. We assume that all individuals between ages 18 and 60 whose labour productivity in a given year equals zero receive a fixed benefit independent of their employment history. Data from the US Department of Labor indicate that the average replacement ratio (definition 1) in the United States is about 47%. However, since entitlements are typically capped at six months and unemployment lasts for one year in our model we have chosen to set the unemployment benefit equal to 25% of average income in the calibration.

Our modeling of the education phase is very stylized and therefore it is not straightforward to choose parameter values for the annual amount of study loan and the tuition fees. Our main goal is to have a realistic level of student debt. To that end we use the average annual loan take up of undergraduate and graduate students in 2012 from the National Center for Education Statistics. This gives an amount of \$11,887 or approximately 24% of average income in the United States in the same year (which is about \$50,000). We set the tuition fee at 40% of this amount to capture the fact that part of the loan cannot be directly consumed. In the United States most types of study loans have no or a very brief grace period, but repayments can be deferred for up to 3 years during periods of unemployment or economic hardship. Although the standard repayment plan for federal loans is 10 years it is possible to arrange an extension up to 30 years. We simplify these provisions somewhat in the model by including a grace period of 4 years for everyone and by setting the redemption period equal to 15 years.

In the second step we calibrate the remaining parameters (Table 2) so as to match certain targets (Table 3). Some of these are quite standard: a capital to output ratio of about 3, an average work week of 40 hours for those who work at least 5,[3] and a net return to capital of 4% per year. We impose that investment and government spending take up 19% and 17% of yearly output, respectively. In addition we normalize the (scaled) return to effective labour

[3]We assume that the unit time endowment of individuals corresponds to about 14 hours a day (excluding sleep and personal care) or 100 hours a week. This means that a 40-hour work week equals 40% of the time endowment.

Table 2: Calibrated parameters

Parameter		Value
Preferences		
Time discount factor	β	0.983
Consumption share in felicity	ε	0.304
Technology		
Capital share in production	ϕ	0.227
Technology level	Φ	0.952
Capital depreciation rate	δ^k	0.036
Government		
Consumption tax rate	τ_t^c	0.070
Income tax rate	$\tau_t^w = \tau_t^r$	0.150
Education		
Location parameter talent for education	μ_θ	0.032
Scale parameter talent for education	σ_θ	0.402
Linear term in return to education	ξ_1	0.253
Quadratic term in return to education	ξ_2	0.001
Leisure cost of studying	$\bar{e}$	0.290
Learning ability		
Strength of experience effect	α	0.638
Location parameter learning ability	μ_γ	0.093
Scale parameter learning ability	σ_γ	0.019
Relation talent for education and learning ability	$\rho_{\gamma\theta}$	0.800
Human capital depreciation		
Level parameter human capital depreciation	δ_0	0.981
Curvature parameter human capital depreciation	δ_1	0.053
Wage uncertainty		
Standard deviation of innovation term	σ_ϵ	0.205

to unity. The target for consumption tax revenue relative to output is taken from the OECD tax database.

The remaining targets require some more elaborate discussion. To calculate the education distribution we use information on educational attainment for individuals age 25 and above from the Current Population Survey (CPS) of 2012. We exclude individuals without a high

Table 3: Model fit on moments targeted by the calibration

	Model	Target	Source
Factor inputs and prices			
Capital to output	2.983	3.000	
Avg. hours worked by employed	40.101	40.000	
Net return to capital	0.040	0.040	
Return to effective labour	1.000	1.000	
Investment to output	0.190	0.190	
Government			
Consumption tax revenue to output	4.454	4.350	OECD for 2012
Government spending to output	0.170	0.170	
Education			
Fraction with 0 years	52.020	53.200	March CPS for 2012
Fraction with 2 years	13.120	11.130	March CPS for 2012
Fraction with 4 years	21.810	22.890	March CPS for 2012
Fraction with 6 years	13.050	12.790	March CPS for 2012
Cohort productivity profiles			
Productivity no college age 25	1.059	1.060	Krueger & Ludwig (2013)
Productivity no college age 35	1.311	1.287	Krueger & Ludwig (2013)
Productivity no college age 45	1.457	1.398	Krueger & Ludwig (2013)
Productivity no college age 55	1.427	1.407	Krueger & Ludwig (2013)
Productivity college age 25	1.509	1.576	Krueger & Ludwig (2013)
Productivity college age 35	2.119	2.243	Krueger & Ludwig (2013)
Productivity college age 45	2.572	2.622	Krueger & Ludwig (2013)
Productivity college age 55	2.672	2.700	Krueger & Ludwig (2013)
College wage premium (in %)	77.583	80.000	Heathcote *et al.* (2010)
Wage uncertainty			
Variance in income growth ($\times 10^3$)	0.357	0.380	Guvenen (2009)
Variance of log earnings at age 50	0.720	0.700	Storesletten *et al.* (2004)

Sources: BLS is the Bureau of Labor Statistics of the United States Department of Labor. CPS is the Current Population Survey. OECD is the Organisation for Economic Co-operation and Development.

school diploma and group those with some college but no degree with the high school graduates ($E = 0$). An associate degree (whether occupational or academic) corresponds to $E = 2$ while a bachelor's degree is $E = 4$. For individuals with a master's degree or above we set $E = 6$. In the resulting distribution more than half of the population has no tertiary education at all, while most of those that attend college obtain a bachelor's degree.

From Krueger and Ludwig (2013) we take two productivity profiles: one for individuals with no college education and one for individuals with some. These are normalized by the average productivity level of a high school graduate at age 23. We include the productivity at ages 25, 35, 45 and 55 for each profile among our targets. This will help us identify the parameters that govern the accumulation of labour market experience and the depreciation of human capital over the life cycle. We make sure that the implied college wage premium, the average hourly wage of individuals with at least 4 years of college education relative to that of individuals who are less educated, is comparable to the one calculated by Heathcote *et al.* (2010) for 2005. Finally, we include two measures of wage uncertainty. The first is the variance of the log of annual labour earnings at age 50 as reported by Storesletten *et al.* (2004). The second one comes from Guvenen (2009) and captures the variability among individuals in the extent to which wages increase with one more year of labour market experience. This corresponds to the variance of γl^{α} in our model.

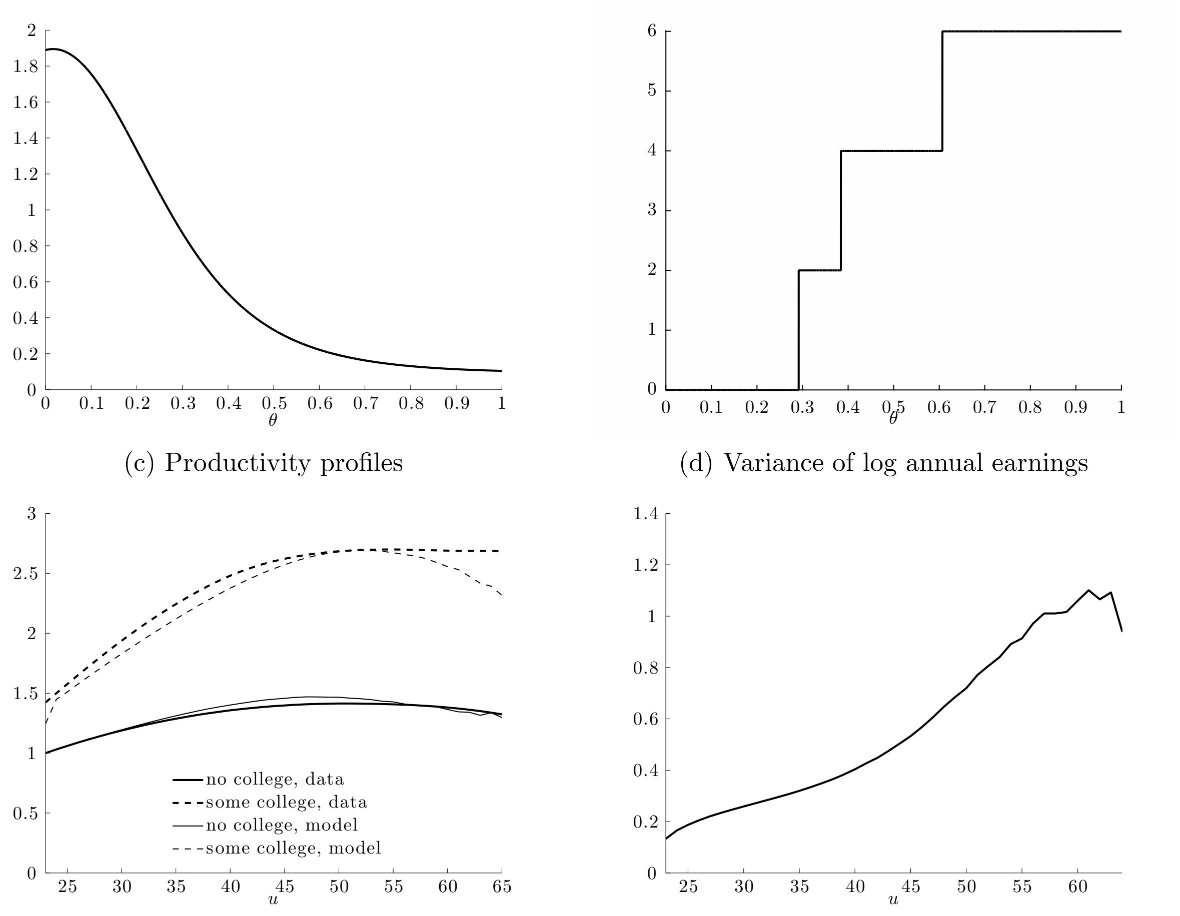
The resulting parameter values are reported in Table 2. The values for μ_γ, σ_γ and α imply that for young individuals the return to experience given a 40-hour work week ranges between 4% and 6% depending on the ability to learn on the job. For older individuals these figures decline because of the ageing effect in human capital depreciation. The return to one year of education for the marginal student (the one who is indifferent between no education at all and 2 years of college) is around 8.5% based on our estimates of ξ_1 and ξ_2.

The model does a good job in matching the targeted moments, as can be seen from Table 3. In particular, the model is able to replicate the bimodal distribution of education levels. In Figure 3 we visualize some of the main features of the calibration. Panel (a) depicts the distribution of educational talent θ. It is single-peaked (by design) and features a lot of mass on the left-hand side and a thin tail at the right-hand side. The optimal education choice is increasing in educational ability as evidenced by panel (b). Figure 3(c) plots the model-generated and actual productivity age-profiles for two groups of people, namely those without a college education ($E = 0$, solid lines) and those with some college ($E > 0$, dashed lines). As the graph shows, the data are matched quite well for the first group and up to age 55 for the second group. Finally, 3(d) depicts the variance of log annual labour earnings by age. Consistent with the data this variance increases smoothly up to about age 57. For higher ages the pattern becomes more irregular as more and more individuals stop supplying hours to the labour market. The convexity of this profile is consistent with the empirical findings of Guvenen (2009).

3.3 Visualization of the base model

In Figure 4 we visualize some of the main life-cycle features of the calibrated base model. Panel (a) shows average consumption for different education levels. Not surprisingly, when all individuals have started to work (i.e., for ages $u \geq M + 6$) the level of consumption at

Figure 3: Calibration outcomes



(a) Distribution of talent

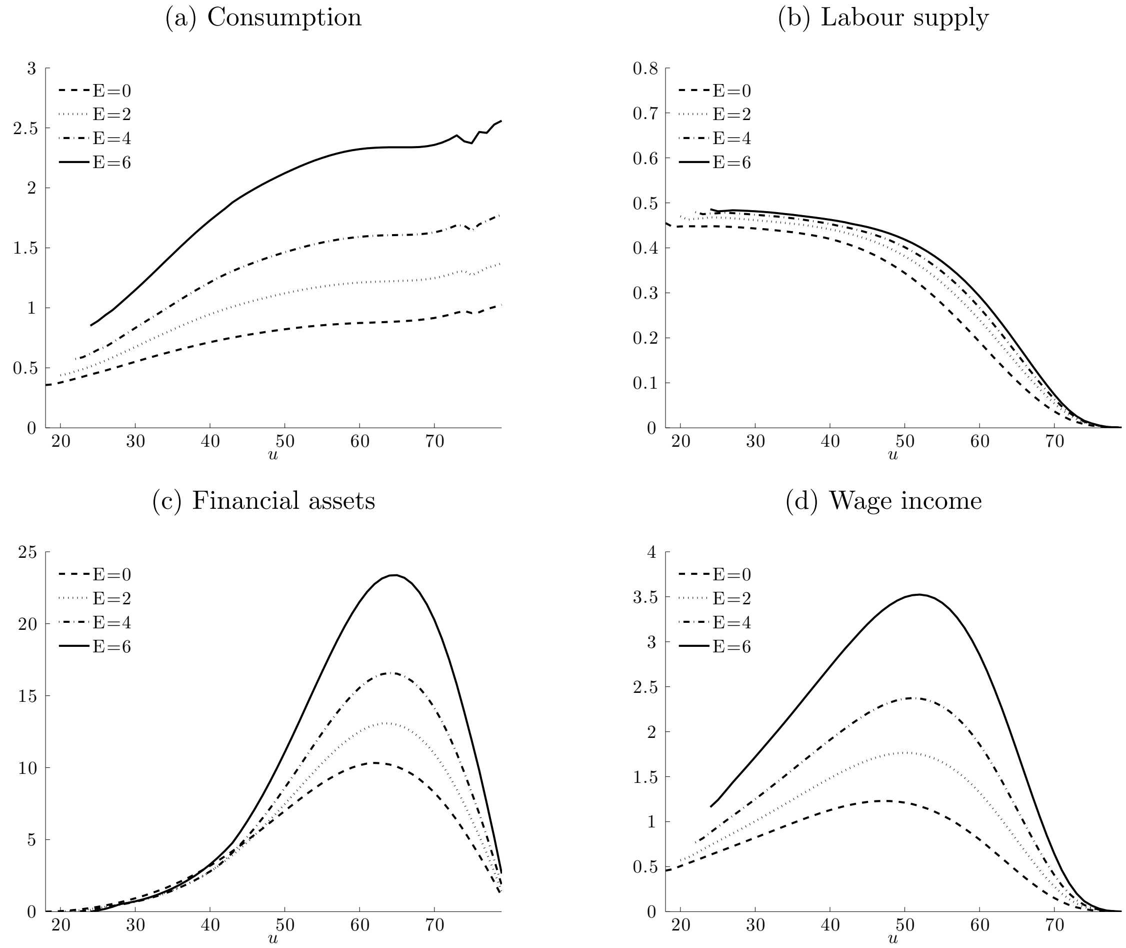
(b) Education choice

(c) Productivity profiles

(d) Variance of log annual earnings

a given age is increasing in the education level. Of course, there may be highly educated individuals (say featuring $E = 6$) who have encountered a lot of bad shocks and enjoy a lower consumption level than a lucky individual of the same age who only completed a bachelor's degree ($E = 4$). But the group averages are monotonic in the education level. In Figure 4(b) the life-cycle labour supply profiles by educational groups are plotted. For ages $u \geq M + 6$ two key features stand out. First, for each educational group average labour supply is roughly constant until middle age sets in. Second, holding age constant, the group-average labour supply is increasing in the education level. Figure 4(c) shows that the age profiles of financial assets in the population are hump shaped. This is not surprising in view of the fact that all individuals start life without financial assets and – in the absence of a bequest motive – plan to expire with zero assets as well. Since we abstract from mortality risk *all* individuals run out of financial assets at the end of their final year of life. Finally, in Figure 4(d) we plot the age profiles for wage income. Obviously, for $u \geq M + 6$ wage income is increasing in the education level. Wage inequality is quite substantial during middle age. Furthermore, as most people have retired at age 70 wage income is close to zero for all educational groups.

Figure 4: Age profiles of cohort averages



4 Reforming the educational financing system

In this section we study a stylized reform of the educational financing system. We start from an economy that is in its steady state and features a mortgage loan (ML) system. At date $t = 0$ the government suddenly stops providing mortgage loans, although existing study debt still has to be redeemed. Instead the government finances transfers to students out of either a comprehensive tax (CT), a graduate tax (GT) or a degree tax (DT) on labour earnings as described in Section 2.3 above.

This reform of the educational financing system affects individual behavior. Individuals respond to the changing incentives by adjusting their education decision, savings, labour supply and consumption. Over time the economy (slowly) converges to a new long-run equilibrium. For each of the three reform scenarios we first discuss the long-run effects in order to develop intuition. Subsequently we show the full transition path and study the welfare effects for pre-reform and post-reform generations. In addition we calculate an aggregate welfare measure and decompose it into several components.

4.1 Long-run implications

4.1.1 Education choices and tax rates

Table 4 shows the long-run changes in the educational composition of the population relative to the initial equilibrium (column "Distr.") when different financing systems are put in place. It also reports the corresponding educational tax rates (column "τ^e").

Table 4: Changes in steady-state education distribution and educational taxes

	CT		GT		DT	
	Distr.	τ^e	Distr.	τ^e	Distr.	τ^e
0 years	−11.12 %p	1.56 %	0.53 %p	0.00 %	−5.79 %p	0.00 %
2 years	−0.28 %p	1.56 %	−12.45 %p	2.37 %	0.65 %p	1.01 %
4 years	1.79 %p	1.56 %	1.29 %p	2.37 %	3.63 %p	1.93 %
6 years	9.61 %p	1.56 %	10.63 %p	2.37 %	1.51 %p	2.67 %

If transfers to students are financed from general labour income taxes (the CT system) we observe a strong increase in educational attainment. The share of individuals who join the labour force directly after high school declines by more than 11 percentage points. At the same time the number of students holding a bachelor degree or higher ($E = 4$ and $E = 6$) rises substantially. The reason for this development is that in the CT system the total population is held liable for financing the cost of education. Even a high school graduate has to pay a 1.56 percent tax on his/her income. This redistribution from the low to the high skilled increases the rate of return of all study paths, so that individuals will consistently choose to obtain higher education degrees.

If instead transfers to students are financed by labour taxes on graduates only (the GT system), the strong decline in the number of high-school educated workers vanishes. However, conditional on obtaining a higher education degree, we find that individuals still tend to choose more education compared to the initial ML system. The logic behind these choices is similar as under the CT system. Redistribution is now limited to the group of educated individuals. Yet, within this group, those with an associate degree ($E = 2$) are overproportionally burdened by the graduate tax and those with a master's degree ($E = 6$) effectively receive a subsidy. Note that due to the number of master students increasing by 10.63 percentage points, the required educational tax rate equals almost 2.4 percent. For the marginal student under the ML system, the one who is indifferent between obtaining an associate degree and directly joining the labour force after high school, the graduate tax even decreases the return to education. This explains the slight rise in the number of workers with only a high school education.

Finally, under the DT reform tax rates are based on the highest degree an individual has obtained. The aim of this tax system is to minimize the extent of redistribution between individuals of different education levels while at the same time allowing for risk sharing among those who pursued the same study path. The tax rates necessary to finance transfers to students now range from roughly 1 percent for individuals holding an associate degree to 2.67 for master graduates. As individuals share the output risk of obtaining higher education, the number of high school workers declines by 5.79 percent while the number of students in all study paths increases.

4.1.2 The macroeconomy and welfare

The long-run macroeconomic consequences of the different policy reforms are illustrated in Table 5. By definition the amount of effective labour employed in a given period is the sum over individuals of the product of their human capital, productivity level and hours. Hence, there are two opposing forces that affect its long-run value. On the one hand, the consistently higher educational attainment of individuals increases their stock of human capital at labour market entry. On the other hand, the educational labour tax distorts the hours decision. Because of the learning-by-doing mechanism, such a distortion also has strong intertemporal effects on the future productivities of workers. Under the CT system the increase in the average years of education is the largest compared to the ML benchmark. Effective labour supply increases by 0.46% under this reform. The increase in average education level is smaller under the GT and the DT system. With a degree tax, effective labour supply even drops by 0.4 percent relative to the initial equilibrium.

When the mortgage loan system is removed, student debt completely disappears, which ultimately leads to a higher capital stock. The difference in the long-run capital level between the three tax systems is essentially due to the differences in net labour earnings and the resulting ability to save. The increase in the capital stock leads to an expansion of economic activity, so that output increases in all scenarios. Finally, while aggregate consumption is larger than in the initial equilibrium under the CT and GT system, in the DT system it drops by 0.45 percent.

With capital becoming relatively abundant, the interest rate falls by around 0.15 percent-

Table 5: Long-run macroeconomic effects

	CT	GT	DT
Macroeconomic quantities			
Effective labour	0.46 %	0.23 %	–0.40 %
Capital stock	3.00 %	2.72 %	1.89 %
Output	1.03 %	0.79 %	0.12 %
Consumption	0.53 %	0.30 %	–0.45 %
Factor prices and taxes			
Wage	0.57 %	0.56 %	0.52 %
Interest rate	–0.15 %p	–0.14 %p	–0.13 %p
Income tax rate	–0.21 %p	–0.14 %p	0.01 %p
Education			
Average years of education	0.64 y	0.44 y	0.25 y
Tuition fees	33.39 %	22.30 %	12.97 %
Welfare			
Compensation	0.10 %	0.37 %	0.36 %

age points and at the same time the wage rate increases by about 0.55 percent in all three reform scenarios. Under the CT and GT system, income tax revenues are boosted owing to an increase in capital and labour income. Consequently, the corresponding income tax rate can decline. Under the DT reform, however, the distortion of labour supply outweighs the revenue effect from higher capital income, so that the income tax rate stays roughly at initial equilibrium levels. In each case there is an increase in the amount of tuition raised because students stay in school longer. For the CT system aggregate tuition payments even rise by a substantial one third.

Finally, the last line of Table 5 reports the long-run welfare effect of the three reform options. We calculate the change in aggregate welfare as compensating variation in ex ante terms and measure it as a fraction of total consumption, details are provided in Section 4.3. We find that the CT system slightly increases long-run welfare by about 0.10 percent of aggregate consumption. The GT system performs best with an increase of 0.37 percent followed closely by the DT system with 0.36 percent.

4.2 Transitional dynamics

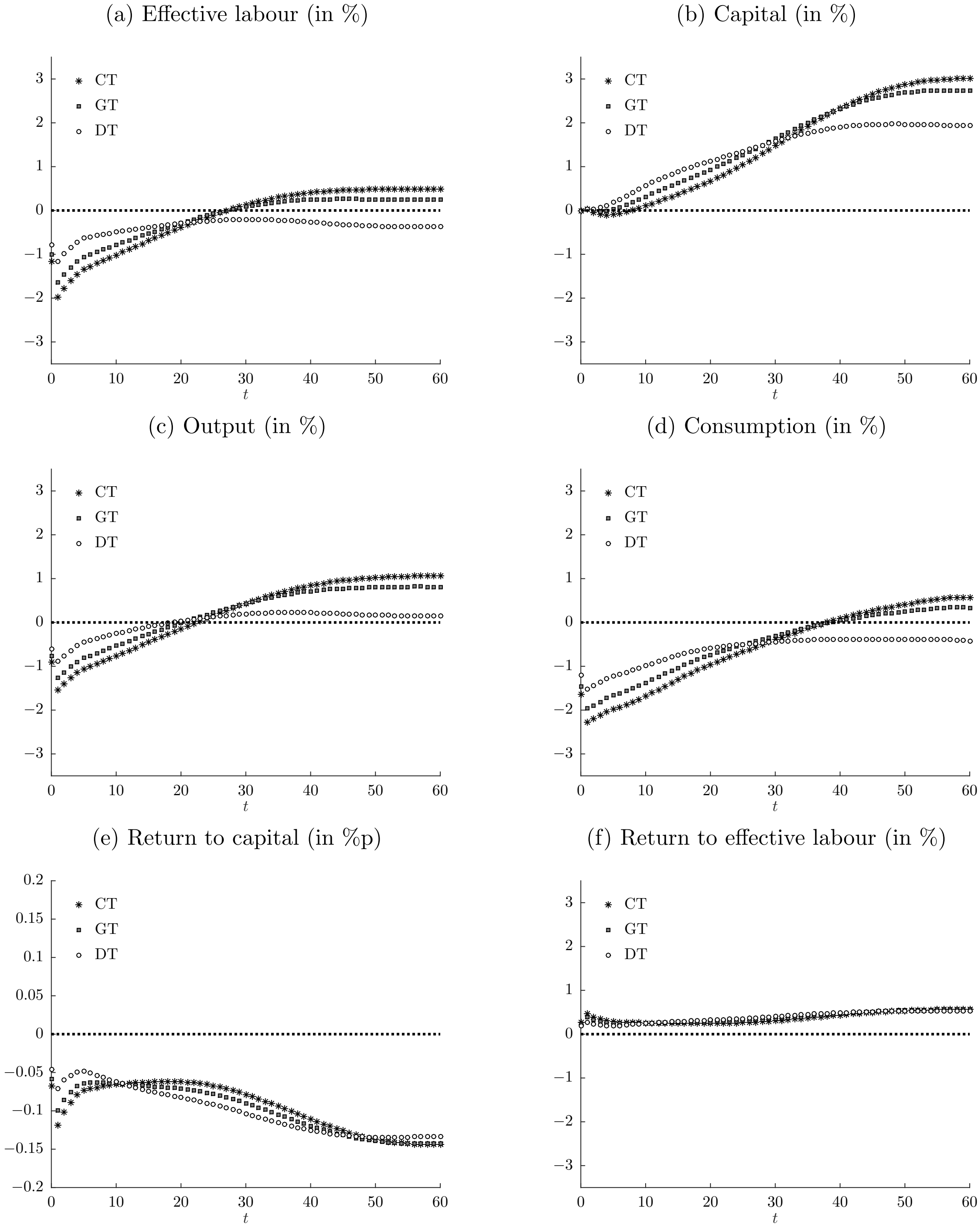
The macroeconomic transition path generated by the policy reforms is illustrated by Figure 5. At the time the reform hits, effective employment drops by 0.79% to 1.16%, depending on the type of policy. In the immediately following period labour supply reaches its maximum reduction at 1.99% (CT), 1.65% (GT), and 1.17% (DT). This is mainly driven by the fact that (i) individuals consistently choose to remain in school for a longer time which has a negative impact on the size of the workforce in the short run (extensive margin) and (ii) the introduction of the educational tax to finance transfers to students reduces average hours worked (intensive margin). Over time workers become increasingly educated and the total amount of effective labour supply starts to rise. In the long-run this leads to higher levels of labour supply under the CT and GT system, while employment always stays below initial equilibrium levels under a DT. The capital stock slowly rises as student loans successively disappear and individuals earn more labour income on average (and consequently have a higher ability to save). Changes in output, consumption and factor prices can be derived from those in effective labour supply and capital.

The fact that there exists a considerable amount of transitional dynamics in the model is not surprising given that there are two slow-moving stocks, namely physical and human capital. Overall, macroeconomic convergence is more or less achieved after fifty years. Note that the transitional dynamics differ quite a bit between the three reforms under consideration. While the CT reform exhibits significant changes in macroeconomic quantities and prices both in the short and in the long run, under a DT system the effects are much less pronounced. Nevertheless, aggregate consumption in the DT system never exceeds its initial equilibrium level, while under other systems total consumption increases in the long run. This, of course, prompts the question concerning the welfare effects of the policy reform. Who are the winners and loser of the change in policy given that its effects are time variable?

4.3 Welfare effects

In order to get a sense of the magnitude of welfare changes along the transition path we adopt the approach suggested by Fehr and Kindermann (2015). We take factor prices and tax rates in each year as given. For every generation we calculate the amount of wealth transfer they should receive in order to make them, from an *ex-ante perspective*, equally well off under the new policy regime as in the initial steady state. The level of ex-ante welfare is calculated one second before individuals reach the age of majority, so that they still face uncertainty about their educational talent θ. Since everyone is identical "behind the veil of ignorance" this approach delivers exactly one transfer level for every cohort. Importantly, we do not want to provide the transfer at a moment in life when individuals are likely to be borrowing

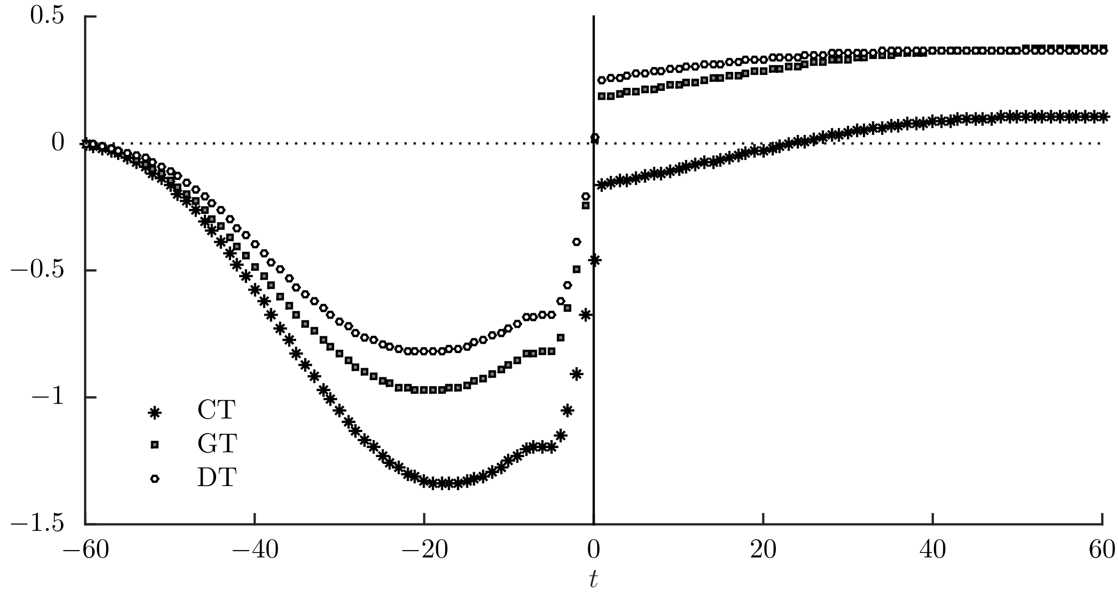
Figure 5: Transitional changes



constrained (during the education phase or shortly thereafter). Therefore we impose that transfers are paid at age 27 (or later if the cohort is older than 27 at time $t = 0$).[4]

In Figure 6 we plot the negative of the transfer levels (corrected for economic growth). A positive number then indicates how much a generation gains from moving to a new policy regime compared to the ML system. To give the figures a more intuitive interpretation, we relate the transfer levels to aggregate consumption in the initial equilibrium. Therefore the welfare gains (or losses) can be thought of as consumption compensating variation.

Figure 6: Compensating transfers



Moving to any tax-based educational financing scheme creates a welfare loss for current working age generations. This follows readily from the fact that these generations are – in a sense – paying the same bill twice. They financed their own education expenses by means of mortgage loans, which some still have to pay back at the time the reform hits. Nevertheless, as any of the tax-based systems is operated on a pay-as-you-go basis, these generations are also burdened by a higher labour income tax. The welfare losses are largest for the CT reform, as the comprehensive labour tax generates a substantial amount of redistribution from unskilled (poor) to skilled (rich) individuals. This regressive redistribution is minimized under the DT system, which is why it creates the smallest welfare losses for existing generations.[5] Students are hurt also, but to a lesser extent the younger they are, as the study debt they have already accumulated is smaller and they can profit more from the new educational financing scheme.

[4]For more details on how the transfer levels are calculated, see Heijdra *et al.* 2014.

[5]Note that since welfare is measured from an ex-ante perspective also for current generations, redistribution from the income poor to the rich does create welfare losses.

Future generations experience welfare gains in all three scenarios, at least in the long-run. Falling interest rates and rising wages contribute to this as the economy moves closer to the golden rule.

The results indicate that some generations gain from our policy reforms while others are worse off (if uncompensated). The question that remains is whether from an *aggregate welfare perspective* these reforms are actually desirable or not. To derive an aggregate measure of welfare from the numbers presented in Figure 6, we calculate the present value of the negative of all the transfers using the (constant) interest rate in the initial steady state r for discounting. This will ensure that the weight given to each generation is independent of the policy reform we simulate. In order to facilitate interpretation we convert this present value into an annuity stream and express it as a percentage of aggregate consumption in the initial steady state. A one percent increase in aggregate welfare therefore is equivalent to a one percent increase in aggregate consumption in each year of the transition and the new long-run equilibrium.[6]

As reported in the final row "Total" of Table 6, the comprehensive tax system creates an aggregate welfare loss of -0.29%, while the GT and the DT system generate an aggregate welfare gain of 0.08% and 0.13%, respectively. Though relatively small, it implies that everybody can be made better off (in an ex-ante sense) if the reform from ML to GT or DT takes place and generations are appropriately compensated.

4.4 Decomposition of aggregate welfare effects

The key mechanisms driving the aggregate welfare effects of our reforms are as follows:

(+) *Risk-sharing opportunity:* As payments in a tax-based educational financing system depend on labour earnings, the output risk of an investment in education can be shared. This improves the welfare of risk-averse educated workers.

(−) *Regressive redistribution:* If transfers to students are financed out of taxes there may be regressive redistribution from the low to the high skilled, depending on the way the tax base is chosen. This reduces welfare from an ex-ante perspective.

(−) *Work incentives:* With an educational labour tax individuals can influence their contributions to the system by working fewer hours. This moral hazard effect creates a distortion of labour supply which negatively impacts aggregate welfare.

(−/+) *Education incentives:* As shown above, all three reforms lead to an increase in average educational attainment. It is however unclear whether this is socially desirable or not.

[6] Fehr and Kindermann (2015) show that the welfare measure we employ is (approximately) equal to considering a social welfare function, in which the ex-ante utility of each generation is weighted with the inverse of its expected marginal utility of consumption. The welfare measure is *neutral* with respect to intergenerational redistribution, meaning that equalizing marginal utilities of consumption across generations does not generate any aggregate welfare gains.

If there was underinvestment in education under the ML system because of risk aversion and the new education financing scheme mitigates this problem by providing suitable risk-sharing opportunities, then we would expect an increase in the number of students to be welfare improving. If, however, individuals decide to prolong their schooling simply because they cannot avoid paying the educational taxes anyway then the number of students may also become inefficiently high, which would depress aggregate welfare.

(+) *General equilibrium:* If interest rates fall, individuals have an incentive to bring consumption forward. As a consequence they might suffer less from borrowing constraints early in life, which generates a positive aggregate welfare effect. Note that changes in factor prices also lead to intergenerational redistribution, but this effect is neutralized in our aggregate welfare measure.

In order to quantify the role of each of these key mechanisms we run several simulations in which we shut down certain adjustment channels. The starting point for each simulation is the steady state equilibrium featuring mortgage loans. The long-run results for all simulations are shown in Appendix A and are expressed in percentage or percentage point changes with respect to this benchmark.

To isolate the effects of risk-sharing and redistribution we fix the interest rate and wage at their initial level by assuming we have a small open economy instead of a closed one. Any differences between output and domestic absorption are attributed to net exports and the discrepancy between domestic asset holdings and the capital stock determines net foreign asset holdings. In addition we keep the distribution of education levels constant so that each θ type makes the same schooling decision as in the benchmark. Finally we let individuals perceive the educational labour tax as being lump-sum to avoid labour supply distortions, while in fact it is proportional to their gross labour income. The aggregate welfare effects of moving from mortgage loans to any of the three tax-based educational financing systems are shown in the first row of Table 6. The CT system generates a welfare loss of -0.17% of aggregate consumption, as negative redistribution outweighs the gains from risk-sharing. Under the GT reform regressive redistribution only happens within the set of students, so that the positive welfare effects from risk sharing weigh stronger. This results in an aggregate welfare gain of 0.14%. Finally, the DT system minimizes regressive redistribution by conditioning tax rates on the highest degree of education obtained by an individual. The increase in aggregate consumption of 0.20% can be viewed as the pure welfare gain from providing adequate risk sharing among students holding the same educational degree. In consequence, the regressive redistribution effect of a comprehensive tax system might be as large as $-0.17\% - 0.20\% = -0.37\%$.

In the next step we keep the assumption of a small open economy and a constant education distribution, but assume that individuals are aware that the tax they pay to finance transfers to students is not lump sum but a percentage of their labour income. As a consequence the tax

Table 6: Comparing the mechanisms: GT versus CT

	CT	GT	DT
Redistribution effect	–0.17 %	0.14 %	0.20 %
Work incentive effect	–0.19 %	–0.18 %	–0.17 %
Educational incentive effect	0.04 %	0.09 %	0.08 %
General equilibrium effect	0.03 %	0.03 %	0.02 %
Total	–0.29 %	0.08 %	0.13 %

not only has an income effect but also a substitution effect which distorts the labour supply decision. In the second row of Table 6 we report the difference between the aggregate welfare numbers of the first and the second set of simulations, which gives the pure work incentive effect of each reform option. We find that the work incentive effects are quite similar under all three systems under consideration. If at all, the DT system performs slightly better than the others. This is a little surprising, as one would think that broadening the tax base and reducing tax rates would be preferable in terms of aggregate welfare. However, recall that in our model the labour supply decision of individuals is not only determined by the tax rate they pay, but also by the prospective return from learning-by-doing. Given the positive correlation between the ability to form human capital in school and on the job, we expect highly educated individuals to have the greatest return to working in terms of future human capital. They will be less responsive to changes in the instantaneous price of labour in the form of higher taxes and therefore have a lower labour supply elasticity. Taxing these highly educated individuals is therefore the least distorting.

For the subsequent simulation we allow individuals to optimally adjust their education decision, but still assume a small open economy. The change in aggregate welfare relative to the previous exercise is shown in the third row of Table 6. We find that the welfare effect from education incentives is smallest (but still positive) in the comprehensive tax system and largest in the GT system. Given the above discussion, this points in the direction that a CT system leads to an inefficiently high level of investment in education compared to GT and DT.

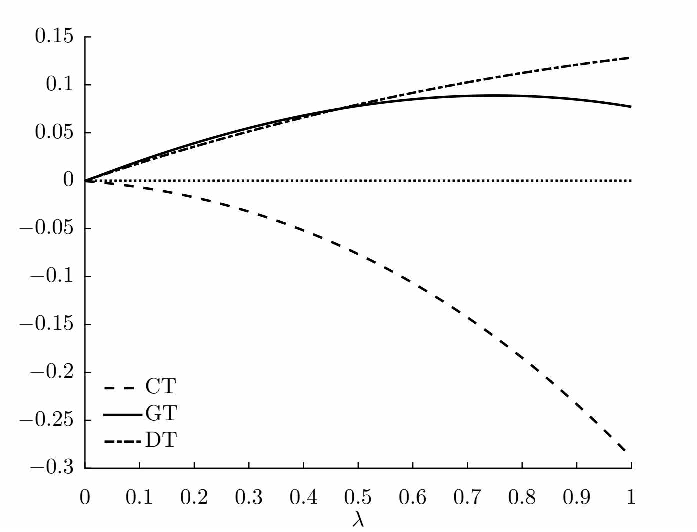
In the final step we reinstate the assumption of a closed economy so that factor prices adjust to changes in domestic demand and supply. The fourth row of Table 6 presents the resulting welfare effects. Overall we find that the decline in interest rates and the resulting alleviation of pressure from borrowing constraints has a small positive impact on aggregate welfare. The effect is the lowest under the DT reform because the interest rate does not decrease as much as in the other scenarios.

We conclude that, in terms of aggregate welfare changes, the work incentive effect constitutes a strong negative component in all systems under consideration. Nevertheless, the positive effect of improved risk-sharing opportunities paired with the education incentive and the general equilibrium effect lead to an overall welfare gain both under the GT and especially the DT system. Only in the CT system, the negative welfare impact of regressive redistribution from the unskilled to the skilled ultimately results in an aggregate welfare loss.

4.5 Hybrid systems

Finally, we want to investigate whether a mixture between mortgage loans and any of the three tax-based educational financing systems might be a favorable option. Let $\lambda \in [0,1]$ be the fraction of each student's transfer income that is paid for out of government tax revenue (either via a CT, GT or DT system), so that $1-\lambda$ has to be financed by mortgage loans. The aggregate welfare effects of these hybrid systems as a function of λ are plotted in Figure 7.

Figure 7: Aggregate welfare change as a function of λ



It turns out that moving to a CT system always generates aggregate welfare losses, regardless of the choice of λ. Therefore even partly financing transfers to students out of comprehensive taxes cannot be recommended. For the GT system we observe a hump shape, implying that it is optimal to cover about 75 percent of transfers to students by revenues from graduate taxes. However, the largest aggregate welfare gain is obtained when completely replacing the existing mortgage loan system by a degree specific tax.

5 Conclusions

In this paper we conduct a quantitative analysis of a number of educational financing systems. We develop a stochastic general equilibrium model of a closed economy with a competitive firm sector and a government that levies taxes and administers educational loans or transfers. Individuals are heterogeneous in their talent for education and ability to learn on the job and face uninsurable idiosyncratic labour productivity risk during their working career.

We calibrate the model to the US mortgage loan system and subsequently consider three possible reforms, all involving labour taxation. The first is a Comprehensive Tax (CT) system under which transfers to students are financed by an additional labour tax on all workers, including those who are uneducated. Under such a system the proportion of uneducated workers drops substantially in the long run. There is an aggregate ex ante welfare loss because of a significant amount of regressive redistribution combined with a negative effect on the incentives to work. The second reform we study is a Graduate Tax (GT) system whereby the educational tax is levied on educated individuals only. We find that in the long run the proportion of uneducated workers stays roughly constant but the average educational attainment of students increases. The ex ante welfare gains to future generations are large enough to – at least in principle – compensate the losers from the policy reform and generate an overall welfare gain. The third reform is a Degree Tax system (DT) which is similar to the GT system except that the educational tax is conditioned on the highest degree attained by the worker. This last system outperforms the other two in aggregate welfare terms.

Overall we conclude that it might be advisable for policy makers in developed countries to consider introducing a degree tax system to finance transfers to students. This system provides valuable risk-sharing among college graduates while at the same time limiting the amount of regressive redistribution. However, as our analysis of the transitional dynamics shows, appropriate compensation of individuals who have already accumulated study debt is crucial in order to prevent them from paying the same bill twice.

Our study leaves room for additional investigation. First of all, one might argue that tax schedules in economies that finance education mostly out of general tax revenue are highly progressive and therefore overproportionally tax the income of high-skilled college graduates. It would be interesting to see to what extent these provide a similar kind of risk sharing as a graduate or a degree tax system. Second, it might also be insightful to investigate whether a linear graduate or degree tax with a basic allowance can push the risk-sharing benefits even further. Computationally this would however be quite challenging because individuals have an incentive to keep their income just below the threshold level. Last but not least our study abstracts from both differences in quality of education across different schools as well as price setting incentives on the side of colleges and universities. A proper modeling of the choices made in the education sector would, however, come at the cost of a less detailed description of the household sector and should therefore be left for future research.

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A Results of the decomposition simulations

Table A.1: Decomposition of long-run changes from ML to CT

	(a)	(b)	(c)	(d)
Small open economy	yes	yes	yes	no
Fixed education	yes	yes	no	no
Individual lump-sum taxes	yes	no	no	no
Macroeconomic quantities				
Effective labour	−0.62 %	−1.52 %	−0.21 %	0.46 %
Capital stock	−0.62 %	−1.52 %	−0.21 %	3.00 %
Output	−0.62 %	−1.52 %	−0.21 %	1.03 %
Consumption	−0.47 %	−1.68 %	−0.14 %	0.53 %
Factor prices and taxes				
Wages	0.00 %	0.00 %	0.00 %	0.57 %
Interest rate	0.00 %p	0.00 %p	0.00 %p	−0.15 %p
Income tax rate	0.00 %p	0.22 %p	−0.06 %p	−0.21 %p
Educational labour tax rate	1.19 %p	1.20 %p	1.59 %p	1.56 %p
Education				
0 years	0.00 %p	0.00 %p	−11.24 %p	−11.12 %p
2 years	0.00 %p	0.00 %p	−0.35 %p	−0.28 %p
4 years	0.00 %p	0.00 %p	1.53 %p	1.79 %p
6 years	0.00 %p	0.00 %p	10.06 %p	9.61 %p
Welfare				
Annuity payment	−0.17 %	−0.36 %	−0.32 %	−0.29 %

Table A.2: Decomposition of long-run changes from ML to GT

	(a)	(b)	(c)	(d)
Small open economy	yes	yes	yes	no
Fixed education	yes	yes	no	no
Individual lump-sum taxes	yes	no	no	no
Macroeconomic quantities				
Effective labour	–0.61 %	–1.51 %	–0.43 %	0.23 %
Capital stock	–0.61 %	–1.51 %	–0.43 %	2.72 %
Output	–0.61 %	–1.51 %	–0.43 %	0.79 %
Consumption	–0.46 %	–1.67 %	–0.36 %	0.30 %
Factor prices and taxes				
Wages	0.00 %	0.00 %	0.00 %	0.56 %
Interest rate	0.00 %p	0.00 %p	0.00 %p	–0.14 %p
Income tax rate	0.00 %p	0.22 %p	–0.06 %p	–0.14 %p
Educational labour tax rate	1.95 %p	1.98 %p	2.41 %p	2.37 %p
Education				
0 years	0.00 %p	0.00 %p	–0.62 %p	0.53 %p
2 years	0.00 %p	0.00 %p	–12.74 %p	–12.45 %p
4 years	0.00 %p	0.00 %p	1.11 %p	1.29 %p
6 years	0.00 %p	0.00 %p	11.01 %p	10.63 %p
Welfare				
Annuity payment	0.14 %	–0.04 %	0.05 %	0.08 %

Table A.3: Decomposition of long-run changes from ML to DT

	(a)	(b)	(c)	(d)
Small open economy	yes	yes	yes	no
Fixed education	yes	yes	no	no
Individual lump-sum taxes	yes	no	no	no
Macroeconomic quantities				
Effective labour	–0.61 %	–1.51 %	–0.99 %	0.46 %
Capital stock	–0.61 %	–1.51 %	–0.99 %	3.00 %
Output	–0.61 %	–1.51 %	–0.99 %	1.03 %
Consumption	–0.46 %	–1.67 %	–1.06 %	0.53 %
Factor prices and taxes				
Wages	0.00 %	0.00 %	0.00 %	0.52 %
Interest rate	0.00 %p	0.00 %p	0.00 %p	–0.13 %p
Income tax rate	0.00 %p	0.22 %p	0.07 %p	0.01 %p
Educational labour tax rate	0.98 %p	1.00 %p	1.03 %p	1.01 %p
	1.87 %p	1.90 %p	1.96 %p	1.93 %p
	2.59 %p	2.64 %p	2.70 %p	2.67 %p
Education				
0 years	0.00 %p	0.00 %p	–5.83 %p	–5.79 %p
2 years	0.00 %p	0.00 %p	0.59 %p	0.65 %p
4 years	0.00 %p	0.00 %p	3.45 %p	3.63 %p
6 years	0.00 %p	0.00 %p	1.79 %p	1.51 %p
Welfare				
Annuity payment	0.20 %	0.03 %	0.11 %	0.13 %