University of Groningen

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

Heijdra, Bernardus; Kindermann, Fabian; Reijnders, Laurie

Published in:
Review of Economic Dynamics

DOI:
[10.1016/j.red.2017.02.006](https://doi.org/10.1016/j.red.2017.02.006)

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version
Publisher's PDF, also known as Version of record

Publication date:
2017

[Link to publication in University of Groningen/UMCG research database](#)

Citation for published version (APA):

Heijdra, B., Kindermann, F., & Reijnders, L. (2017). Life in shackles? The quantitative implications of reforming the educational loan system. *Review of Economic Dynamics*, 25, 37-57.
<https://doi.org/10.1016/j.red.2017.02.006>

Copyright

Other than for strictly personal use, it is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license (like Creative Commons).

The publication may also be distributed here under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license. More information can be found on the University of Groningen website: <https://www.rug.nl/library/open-access/self-archiving-pure/taverne-amendment>.

Take-down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Downloaded from the University of Groningen/UMCG research database (Pure): <http://www.rug.nl/research/portal>. For technical reasons the number of authors shown on this cover page is limited to 10 maximum.

Life in shackles? The quantitative implications of reforming the educational financing system [☆]

Ben J. Heijdra ^{a,c,d,1}, Fabian Kindermann ^{b,c,*}, Laurie S.M. Reijnders ^{a,c,1}

^a University of Groningen, The Netherlands

^b University of Bonn, Germany

^c Netspar, The Netherlands

^d CESifo (Munich), Germany

ARTICLE INFO

Article history:

Received 23 March 2016

Received in revised form 16 December 2016

Available online 16 February 2017

JEL classification:

E10

E24

D91

I22

J24

Keywords:

Education

Human capital

Study loans

Uninsured labor market risk

Incomplete markets

Overlapping generations

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 United States economy, including a stylized version of its student loan system. We find that moving to an income-contingent educational financing system, whereby transfers to students are financed from taxes on labor income, generates aggregate welfare gains. Such a system improves risk-sharing among college graduates and incentivizes individuals to obtain more education. These positive effects overturn the negative impact from labor supply distortions. Reforming the educational financing system towards income contingency, however, generates a considerable amount of transitional dynamics, so that welfare gains and losses are distributed unevenly across generations.

© 2017 Elsevier Inc. All rights reserved.

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)]

[☆] We thank the editor Dean Corbae, our discussant Giovanni Gallipoli, two anonymous referees as well as Bas Jacobs, Lance Lochner and Rick van der Ploeg for helpful comments and suggestions. We are grateful to Hans Fehr for funding Heijdra's research visit to Würzburg. This paper was presented at the CESifo Area Conference on Public Sector Economics (April 2015, Munich), the World Congress of the Econometric Society (August 2015, Montreal), the Human Capital and Inequality Conference of the HCEO (December 2015, Chicago) and the Macro Seminar at ANU (February 2016, Canberra).

* Corresponding author at: Institute for Macroeconomics and Econometrics, University of Bonn, Adenauerallee 24-42, 53113 Bonn, Germany.

E-mail addresses: b.j.heijdra@rug.nl (B.J. Heijdra), fabian.kindermann@uni-bonn.de (F. Kindermann), l.s.m.reijnders@rug.nl (L.S.M. Reijnders).

¹ University of Groningen, Faculty of Economics and Business, P.O. Box 800, 9700 AV Groningen, The Netherlands.

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 a student 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, student loans have become an increasingly important source of funds to finance a college education in the United States. 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. One of the major components of this risk is the considerable amount of heterogeneity in earnings of successful college graduates. To deal with this, researchers have argued that income-based repayments should be preferred over standard student loans, as they at least partially insure individuals against the risk of a low return to a college education. 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 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 labor 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 labor productivity shocks, including the possibility of (temporary) unemployment. This implies that labor 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 labor market experiences.

We calibrate our model to the United States economy around the year 2010, including a stylized version of its student loan (SL) system. In this system the transfers that a student has received during the education phase constitute the debt that he or 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 labor earnings collected through the progressive tax system. A graduate tax is a proportional tax that is only levied on educated individuals. Finally, a degree tax differentiates by the highest degree earned, thereby 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 SL 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 or she actually pursues. This regressive redistribution substantially increases the return to a college education. In a reform from SL 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 minimizes the extent of redistribution between individuals of different education levels and a reform from SL to DT results in a moderate increase in average educational attainment.

Second, all three reforms produce significant long-run effects on the macroeconomy. When the student loan system is removed, the corresponding debts disappear which – taken in isolation – leads to an increase in the capital stock. The reduction in precautionary savings that results from a better provision of risk-sharing opportunities does not compensate for this, so that the interest rate falls and wages rise. Aggregate consumption increases by, respectively, 1.55% and 0.77% under the reforms CT and GT but stays more or less constant in the reform from SL to DT. Ex-ante welfare, by which we mean the level of welfare an individual expects before his or her talent for learning in school is revealed, increases in the long run under all reforms but the most for GT. When we look at ex-post welfare by type we see that the CT system, which holds all individuals liable for the costs of education, hurts the low ability types who do not participate in education themselves. In contrast, DT and GT increase steady-state welfare for everyone.

Third, in addition to the 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 considerable heterogeneity in welfare effects across different generations along the transition path. For generations that are already economically active at the time of the reform ex-ante 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 student loan, but are also hit by a higher labor-income tax. Students are hurt as well, but to a lesser extent the younger they are (and thus the lower is the already incurred student loan). When aggregating welfare effects across all affected generations, it turns out that for all systems the gains of post-shock cohorts are large enough to compensate the losers from the policy reform so that aggregate welfare increases. However, the aggregate welfare effects are quite different in size, so that GT performs best and CT worst.

Fourth, 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 labor supply so that there is a negative work-incentive effect. This is however more than compensated by a positive educational-incentive effect, which suggests that there was underinvestment in education under the SL system. Whether the redistribution effect of each reform is positive or negative depends on the type of redistribution it generates: risk-sharing between college graduates (positive effect on welfare) or regressive redistribution from uneducated to educated workers (negative effect on welfare). For the CT system the latter effect dominates, which explains why the aggregate welfare effect is lowest for this reform (albeit still positive). The general equilibrium effect due to changes in factor prices is positive but small in all three scenarios.

Finally, we investigate whether a hybrid system of graduate and degree taxes paired with a proportional tax on the total work force can do better in terms of aggregate welfare. If the share of expenses financed by any of the three taxes is not restricted in any way then the best hybrid system features a subsidy to individuals who only hold a high school degree. The welfare-maximizing policy thus redistributes ex-post surplus to individuals who do not participate in higher education at all – a point often ignored in the discussion regarding the advantages of tax-based policies. The resulting aggregate welfare gain is even larger than under a pure graduate tax.

1.1. Educational financing in theory and practice

If borrowers are risk averse and lenders 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 favors 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). Friedman 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. In our model set-up, 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.

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 a recent 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 provisions 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. This limits the degree of risk sharing among college graduates in these programs.

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-Peñalosa and Wälde \(2000\)](#), [Jacobs and van Wijnbergen \(2007\)](#), [Cigno and Luporini \(2009\)](#), [Del Rey 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. \(2016\)](#). Of these, the paper by [Abbott et al. \(2016\)](#) is most closely related to ours. Although both papers use a common quantitative methodology, their focus is quite distinct. For example, [Abbott et al. \(2016\)](#) include a detailed description of how individuals decide about education and what exactly their resources are during the schooling period, i.e. both student loans and borrowing constraints are modeled in detail. In addition, they include inter vivos 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 behavior 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 labor 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:

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

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 labor employed in production. This effective labor is the sum of the labor supplied by different individuals with an adjustment for their education level and productivity (see also below).² Z_t is an index of labor-augmenting technological change which is assumed to grow at a constant and exogenous rate $n^z > 0$.³ The parameter ϕ captures the income share of capital while Φ is used for normalization. The firm's stock of physical capital increases with investment I_t and depreciates at a constant rate δ^k so that $K_{t+1} = (1 - \delta^k)K_t + I_t$. The real profit flow at time t is given by $Y_t - w_t N_t - (r_t + \delta^k)K_t$ with r_t the interest rate and w_t the rental rate on effective labor. The profit-maximizing mix of inputs gives rise to the following marginal productivity conditions:

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

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

2.2. Individuals

2.2.1. Stochastic environment over the life cycle

Each individual lives with certainty from age $u = 0$ up to age $u = \bar{U}$. He or she graduates from high school at the age of majority M and starts making economic decisions from that date onward. The sequence of events in a person's life is summarized in Fig. 1.

At the age of majority M the innate talent for education, θ , is drawn from a distribution with support $[0, 1]$. The higher is θ , the greater will be the return to tertiary education experienced by the individual. Upon completion of the education phase at age $M + E$, the individual enters the working phase. His or her ability to learn on the job is then revealed, which we denote by γ . We assume that the learning-by-doing parameter can take on two values, $\gamma \in \{\gamma_l, \gamma_h\}$ with $0 < \gamma_l < \gamma_h < 1$. It is positively correlated with θ so that an individual who is very talented at school is also likely to learn quickly on the job.

During the working phase there is a draw for the idiosyncratic labor 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 education level. We incorporate some real-world features into this simple Markov scheme which we find relevant for workers who may have a sizable student loan. 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 United States (such as persistence and variability – see below). The first draw of η upon labor market entry is equal to unity, which we call average productivity. We impose a lot of additional structure on the Markov process in that (i) any productive worker can become unemployed, (ii) barring moves to unemployment a productive worker can only move up or down by a single state level, and (iii) a previously “unemployed” individual moves to the average productivity level or stays unemployed. This is

² In an online appendix we show how our results change when we allow for imperfect substitutability between labor with different levels of education.

³ Note that due to the specification of our production function and the fact that the number of labor hours an individual can provide is limited, labor-augmenting technological change and changes in total factor productivity are from a technical standpoint identical.

Fig. 1. The individual's life cycle.

Fig. 2. Markov process for labor productivity η .

summarized in Fig. 2, where there is only a directed arrow from one state to another if there is a positive probability of transition between them.

Individuals are assumed to be fully aware of the stochastic environment they live in and to be able 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.

2.2.2. Optimal decisions of a worker

Consider a worker who is of age u , has enjoyed E years of education and whose learning-by-doing parameter equals γ . At the start of year t this individual owns stocks of financial assets a and human capital h and draws a labor productivity level η . He or she chooses current consumption c and labor supply l as well as next period's financial assets a^+ and human capital h^+ in order to maximize remaining lifetime utility. The optimization problem is characterized by the Bellman equation:

$$V_{u,t}(E, \gamma, a, h, \eta) = \max_{c, l, a^+, h^+} \left\{ \left[c^\varepsilon (1-l)^{1-\varepsilon} \right]^{1-1/\sigma} + \beta \left[\mathbb{E}_{\eta^+ | \eta, E} \left[V_{u+1, t+1}(E, \gamma, a^+, h^+, \eta^+)^{1-\zeta} \right] \right]^{\frac{1-1/\sigma}{1-\zeta}} \right\}^{1-1/\sigma}. \quad (3)$$

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

$$a^+ = [1 + (1 - \tau_t^r)r_t]a + \mathcal{W}_t(w_t\eta hl) + v_{u,t}\mathbb{1}_{\{\eta=0\}} - (1 + \tau_t^c)c - \Upsilon_{u,t}(E, w_t\eta hl), \quad (4a)$$

$$h^+ = (1 - \delta_u^h)[1 + \gamma l^\alpha]h, \quad (4b)$$

$$0 \leq l \leq 1, \quad c \geq 0, \quad a^+ \geq 0, \quad (4c)$$

where β is the time discount factor ($0 < \beta < 1$) and τ_t^r and τ_t^c are proportional tax rates on, respectively, interest income and consumption. Several things are worth noting. First, 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 *intertemporal* substitution elasticity ($\sigma > 0$) whilst ζ captures the degree of relative risk aversion ($\zeta \geq 1$). 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. Second, the preference structure in (3) satisfies the King–Plosser–Rebelo conditions (see [King et al., 2002](#)) so that – in the presence of ongoing labor productivity growth – a stationary decision problem is obtained by scaling the individual's consumption and financial assets (as well as wages, unemployment benefits, and education payments) by an index of productivity. See [Heijdra et al. \(2014\)](#) for details. Third, the expectation $\mathbb{E}_{\eta^+|\eta,E}$ is with respect to next period's labor productivity η^+ and conditional on information about current productivity η and the education level E .

Expression (4a) is the budget identity, which states that the change in financial assets is equal to after-tax earnings minus spending. Earnings consist of both capital and labor income plus an unemployment benefit $v_{u,t}$ that is paid out when labor productivity is zero (so that the indicator function $\mathbb{1}_{\{\eta=0\}}$ is equal to one). In addition to consumption expenditures the individual is required to pay an amount $\Upsilon_{u,t}(E, W)$ to the educational financing system which depends on his or her age u , education E and gross wage income W . The function $\mathcal{W}_t(W)$ translates gross labor earnings W into net income:

$$\mathcal{W}_t(W) = (1 - \tau_t^{w,0})W^{1-\tau^{w,1}}, \quad 0 < \tau_t^{w,0} < 1, \quad 0 < \tau^{w,1} < 1. \quad (5)$$

The implied (progressive) tax schedule dates back to [Feldstein \(1969\)](#) and has recently been used for example by [Heathcote et al. \(2014\)](#). Note that $\tau^{w,1}$ is an index of progressivity and $\tau_t^{w,0}$ determines the total amount of revenue that the government generates from labor earnings taxation.

Expression (4b) shows that the accumulation of human capital during the working phase depends on two distinct mechanisms. The *learning-by-doing effect* is captured by the term γl^α . Conditional on the individual's learning-by-doing parameter γ , more experience is gained the more he or 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, 2016](#)). In particular, for $M \leq u \leq \bar{U}$ we postulate:

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

The expressions in (4c) show that labor 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).⁴

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.⁵ Tertiary education starts at age M and requires a fixed time input of $\bar{e}$ each period. It is not possible to work and study at the same time, so that leisure during the educational phase is equal to the remainder of the unit time endowment $1 - \bar{e}$. In the absence of labor 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 .⁶ In addition we assume for simplicity that consumption during the educational phase is also fixed, i.e. c_t is the remainder of the transfer after paying the tuition fee:

⁴ Note that the assumption of a tight borrowing constraint restricts individuals only from accumulating any uncollateralized debt. Taking up a mortgage for a house, for example, typically increases the net asset position of individuals and therefore would be perfectly consistent with our set up (although we do not explicitly consider different kinds of asset holdings).

⁵ The assumption that individuals do not receive any transfers from their parents is certainly strong and restrictive. Nevertheless, it allows us to provide a more detailed modeling of the phase after tertiary education. In addition, including inter vivos transfers from parents comes along with a whole set of further considerations and complications, see [Abbott et al. \(2016\)](#).

⁶ In recent years, tuition fees for many institutions have increased at a much higher rate than economic growth. However, we need to make this assumption to guarantee that the economy converges to a steady state in the long-run.

$$c_t = \frac{q_t - f_t}{1 + \tau_t^c}. \quad (7)$$

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 labor market entry for a person with educational talent θ and years of education E is given by:

$$\Gamma(\theta, E) = 1 + \xi_1 \theta E - \xi_2 [1 - \theta] E^2, \quad \xi_1 > 0, \quad \xi_2 > 0. \quad (8)$$

Note that individuals with a higher ability level experience weaker diminishing returns to education. This ensures that the optimal education choice is increasing in ability. 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:

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

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). At labor 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 identity (4a). We consider four stylized systems. The base case is the student loan (SL) system in which individuals pay off their own student loan during their working career. In the three alternative scenarios 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) they are paid out of general labor tax revenue. 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.

SL Student loans

With student loans the payment $\Upsilon_{u,t}(E, W)$ does not depend on wage income W . At each moment in time the size of the loan $\Omega_{u,t}(E)$ 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 student loan increases as a result of interest payments on existing debt and exogenous loan inflows (the transfer q_t 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 student loans are tax deductible from asset income. However, since students do not earn any 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 $\bar{u}(E)$, the *redemption period*. If $\underline{u}(E) > M + E$ then there is a *grace period* so that payments do not start immediately once the individual leaves school. 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 $\bar{u}(E) + 1$ if the payment remains constant during the remainder of the redemption period. Default does not happen because (i) there is a (small) unemployment insurance system in place which covers periods with zero labor productivity and (ii) 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 out of general tax revenue the payment $\Upsilon_{u,t}(E, W)$ does not depend on education E directly:

$$\Upsilon_{u,t}(E, W) = \tau_t^e W^{1-\tau^{w,1}}.$$

However, as educated individuals tend to earn higher gross wages and the tax system is progressive they 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, labor income and capital income to finance (intrinsically useless) public consumption G_t and unemployment benefits B_t . We abstract from debt financing, so that in each period total tax revenues should equal total expenditures.⁷

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 C_t is total individual consumption and F_t is the amount of tuition fees paid. Second, the capital market equilibrium condition states that the productive capital stock is equal to total savings A_t net of student loans D_t :

$$K_t = A_t - D_t.$$

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

$$N_t = L_t,$$

where L_t is total over individuals of their effective labor supply $\eta h l$. 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 $\mathbb{P}(\gamma = \gamma_h | \theta) = 0.5 + \rho_{\gamma\theta} [F_\theta(\theta) - 0.5]$ 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

⁷ In an online appendix we show how our results change when we allow the government to use public debt in order to smooth the costs of a policy reform over time.

Table 1
Parameters taken from data or literature.

Parameter		Value	Source
<i>Preferences</i>			
Intertemporal substitution elasticity	σ	0.5	İmrohoroglu and Kitao (2009)
Coefficient of relative risk aversion	ζ	4.0	Cecchetti et al. (2000)
<i>Demography</i>			
Age of majority	M	18	
Maximum age	$\bar{U}$	79	WB for 2012
Population growth rate	n^p	0.007	WB for 2012
<i>Technology</i>			
Economic growth rate	n^z	0.020	FRED for 1970–2006
<i>Wage uncertainty</i>			
Autocorrelation risk process	ρ_η	0.962	Güvenen et al. (2015)
Variance of innovation term	σ_ϵ^2	0.030	Güvenen et al. (2015)
<i>Unemployment</i>			
Probability exiting unemployment	κ	0.990	
Probability entering unemployment			March CPS for 2000–2006
– 0 years of education	$\pi(0)$	0.048	
– 2 years of education	$\pi(2)$	0.035	
– 4 years of education	$\pi(4)$	0.027	
– 6 years of education	$\pi(6)$	0.019	
<i>Student loans</i>			
Annual loan to average income		0.238	NCES for 2012
Tuition fee as fraction of loan		0.400	
Length of grace period		4	
Length of redemption period		15	
<i>Government</i>			
Labor tax progressivity	$\tau^{w,1}$	0.151	Heathcote et al. (2014)
Unemployment benefit to average income		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.

the unconditional mean and variance are given by $\mathbb{E}[\gamma] = \mu_\gamma$ and $\text{Var}(\gamma) = \sigma_\gamma^2$. Finally we have to specify the transition matrix for the Markov process that governs idiosyncratic labor 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., $\eta > 0$) labor productivity should mimic a log-AR(1) process with autocorrelation ρ_η and a stochastic innovation term with variance σ_ϵ^2 . For the resulting transition matrix, see Heijdra et al. (2014).

3.2. Parameter values

We calibrate the steady state of the model under the student loan system to fit some key features of the United States economy around 2010 using a two-step procedure. First we assign values to a subset of the parameters that are taken directly from the data or the literature, see Table 1. İmrohoroglu 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 ζ 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 $n^p = 0.74\%$ for the United States. The maximum age $\bar{U}$ 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 Bank (measured in 2011 US dollars) and regress its log on a time variable. The resulting coefficient equals 0.02 or 2% per year, which is our estimate for n^z .

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 ρ_η and variance σ_ϵ^2 of the labor productivity process from Güvenen et al. (2015), who use an administrative data set of labor earnings for the United States and allow for heterogeneity in income growth rates (HIP model). 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.

Table 2
Calibrated parameters.

Parameter		Value	Parameter		Value
<i>Preferences</i>			<i>Talent for education</i>		
Time discount factor	β	0.984	Location parameter	μ_θ	0.250
Consumption share in felicity	ε	0.353	Scale parameter	σ_θ	0.415
Leisure cost of studying	$\bar{e}$	0.153			
			<i>Learning ability</i>		
<i>Technology</i>			Strength of experience effect	α	0.615
Capital share in production	ϕ	0.227	Location parameter	μ_γ	0.091
Technology level	Φ	0.952	Scale parameter	σ_γ	0.020
Capital depreciation rate	δ^k	0.036	Correlation learning ability	$\rho_{\gamma\theta}$	0.800
			<i>Return to education</i>		
<i>Government</i>			Linear term	ξ_1	0.251
Consumption tax rate	τ^c	0.070	Quadratic term	ξ_2	0.0001
Labor tax rate	$\tau^{w,0}$	0.061			
Capital tax rate	τ^r	0.147			
			<i>Human capital depreciation</i>		
			Level parameter	δ_0	0.980
			Curvature parameter	δ_1	0.055

Our modeling of the education phase is very stylized and therefore it is not straightforward to choose parameter values for the annual amount of student loans and the tuition fees. Our main goal is to have a realistic level of student loans. 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.⁸ In the United States most types of student 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.

Heathcote et al. (2014) use individual level data from the PSID to estimate the relationship between gross and net income in the United States using the progressive tax schedule described above. Their estimate of the progressivity parameter is $\tau^{w,1} = 0.151$. Data from the US Department of labor indicate that the average replacement ratio (definition 1) for the unemployment insurance 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.⁹

In the next 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 5,¹⁰ 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 labor 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 of age 25 and above from the Current Population Survey (CPS) of 2012. We exclude individuals without a high 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. We include the productivity at ages 25, 35, 45, 55 and 65 for each profile among our targets. This helps us identify the parameters that govern the accumulation of labor 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 as a measure of wage uncertainty the variance of the log of annual labor earnings at age 50 as reported by Guvenen et al. (2015).

⁸ This would amount to a yearly tuition fee of about \$4,700, which is close to the average value of \$4,413 as reported by Heckman et al. (2008) for the United States in 2000.

⁹ There are two reasons for including such a simple employment insurance system. First, it prevents individuals from working 'too hard' and saving 'too much' in the years immediately following graduation compared to the data. Second, without any redistribution towards the unemployed we are likely to overstate the welfare benefits from reforming the educational financing system in such a way that it offers more insurance against low income periods.

¹⁰ 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 3

Model fit on moments targeted by the calibration.

	Model	Target	Source
<i>Factor inputs and prices</i>			
Capital to output ratio	3.00	3.00	
Average hours worked by employed	40.00	40.00	
Interest rate (in %)	4.00	4.00	
Return to effective labor of each type	1.00	1.00	
Investment to output (in %)	19.00	19.00	
<i>Government</i>			
Consumption tax revenue to output (in %)	4.46	4.35	OECD for 2012
Government spending to output (in %)	17.00	17.00	
<i>Education</i>			
Share of the population			March CPS for 2012
– 0 years of education (in %)	53.03	53.20	
– 2 years of education (in %)	11.80	11.13	
– 4 years of education (in %)	22.41	22.89	
– 6 years of education (in %)	12.76	12.79	
College wage premium (in %)	85.75	80.00	Heathcote et al. (2010)
<i>Cohort productivity</i>			
Productivity profile no college			Krueger and Ludwig (2013)
– age 25	1.07	1.06	
– age 35	1.37	1.29	
– age 45	1.53	1.40	
– age 55	1.45	1.41	
– age 65	1.21	1.32	
Productivity profile some college			Krueger and Ludwig (2013)
– age 25	1.52	1.58	
– age 35	2.25	2.24	
– age 45	2.82	2.62	
– age 55	2.93	2.70	
– age 65	2.43	2.69	
<i>Wage uncertainty</i>			
Peak income variance	0.85	0.86	Guvenen et al. (2015)

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.

In total, we use 23 calibration targets and have 19 parameters to match them. By imposing the additional restriction that the average tax rates on labor earnings and capital income are identical there are 18 free parameters left. The resulting parameter values are reported in Table 2. The values for μ_Y , σ_Y and α imply that for young individuals the return to experience given a 40-hour work week ranges between 4.04% and 6.32% 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 average internal rate of return of a four-year college education (including tuition and progressive taxes) is 12.3% in the model, which is close to the estimate of 13% reported by Heckman et al. (2008) for white males in the United States in 2000.

The model does a good job in matching the targeted moments, as can be seen from Table 3. In Fig. 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. Fig. 3(b) 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 model-generated productivity profiles are more hump shaped than what we observe in the data. Nevertheless, the model is able to replicate the differences in steepness at the beginning of working life between no college and some college workers and provides a reasonable match for labor productivity of the two groups on average.

3.3. Visualization of the base model

In Fig. 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 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 high school ($E = 0$). Nevertheless, the group averages are monotonic in the education level. In Fig. 4(b) the life-cycle labor supply profiles by educational groups are plotted. For ages $u \geq M + 6$ two key features stand out. First, for each educational group average labor supply is roughly constant until middle age sets in. Second, holding age constant, the group-average labor supply is increasing in the education level. Fig. 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 individ-

Fig. 3. Calibration outcomes.

uals start life without financial assets and – in the absence of a bequest motive – plan to expire with zero assets as well. Finally, in Fig. 4(d) we plot the age profiles for wage income. Obviously, for $u \geq M + 6$ average 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. Overall our model underestimates the unequal distribution of labor income and wealth quite a bit. The respective Gini indices are 0.52 and 0.58 compared to data estimates of 0.67 and 0.85 as provided for example by Kuhn and Rios-Rull (2015). The reason is that we do not explicitly target top income inequality. To accurately paint a picture of the top tail of the earnings and wealth distribution, further model extensions like in Guner et al. (2014) or Kindermann and Krueger (2014) would be necessary.

4. Reforming the educational financing system

In this section we study a stylized reform of the educational financing system. We start from the calibrated economy that is in its steady state and features a student loan (SL) system. At date $t = 0$ the government suddenly stops providing student loans, although existing loans still have 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 labor 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, labor supply and consumption. Over time the economy (slowly) converges to a new long-run equilibrium. 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 different 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 “share”) when different financing systems are put in place. It also reports the corresponding educational tax rates (column “ τ^e ”).¹¹

If transfers to students are financed from general labor income taxes (the CT system) we observe a strong increase in educational attainment. The share of individuals who join the labor force directly after high school declines by more than 12 percentage points. At the same time the number of students holding a masters degree or higher ($E = 6$) 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. While the taxes used to fund grants to students are collected in a progressive manner, they solely depend on individual income and are not conditioned on educational attainment. Hence, even a high school graduate with a reasonably good performance in the labor market faces a significant rise in taxes on his or her income. This redistribution from the low to the high skilled increases the rate of return to education, so that individuals will consistently choose to obtain higher education degrees.

¹¹ In case of the CT reform, the reported tax rate corresponds to the change in the average tax rate of the labor income tax schedule, since we leave the degree of progressivity unaltered.

Fig. 4. Age profiles of cohort averages.

Table 4

Changes in steady-state education distribution and educational taxes.

	CT		GT		DT	
	Share	τ^e	Share	τ^e	Share	τ^e
0 years	−12.45%p	1.68%	−1.53%p	0.00%	−7.37%p	0.00%
2 years	−2.17%p	1.68%	−11.80%p	2.25%	−0.53%p	0.93%
4 years	−0.07%p	1.68%	−2.13%p	2.25%	3.68%p	1.78%
6 years	14.69%p	1.68%	15.46%p	2.25%	4.22%p	2.46%

If instead transfers to students are financed by proportional labor 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 SL 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 more than proportionally 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 15.46 percentage points, the required educational tax rate equals 2.25 percent.

Finally, under the DT reform tax rates are based on the highest degree an individual has obtained. This implies that the extent of redistribution between individuals of different education levels is minimized while at the same time there is risk sharing among those who pursued the same degree. The tax rates necessary to finance transfers to students now range from roughly 1 percent for individuals holding an associate degree to 2.46 for master graduates. As individuals share the risk of obtaining higher education, the number of high school workers declines by 7.37 percent while the number of bachelor and master students increases.

Table 5
Long-run macroeconomic effects.

	CT	GT	DT
<i>Macroeconomic quantities</i>			
Effective labor	1.27%	0.62%	−0.09%
Capital stock	3.92%	3.07%	2.17%
Output	1.87%	1.17%	0.42%
Consumption	1.55%	0.77%	−0.10%
<i>Factor prices and taxes</i>			
Wage	0.59%	0.55%	0.51%
Interest rate	−0.15%p	−0.14%p	−0.13%p
Average income tax rate	−0.39%p	−0.23%p	−0.07%p
<i>Education</i>			
Average years of education	0.83y	0.60y	0.39y

Changes are reported relative to the benchmark scenario with student loans, either in percentages (%), percentage points (p) or years (y).

4.1.2. The macroeconomy

The long-run macroeconomic consequences of the different policy reforms are illustrated in Table 5. By definition the amount of effective labor 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 labor market entry. On the other hand, the educational labor 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 SL benchmark. Effective labor supply increases by 1.27% under this reform. The increase in average education level is smaller under the GT and the DT system. With a degree tax, effective labor supply even drops by 0.09 percent relative to the initial equilibrium.

When the student loan system is removed, the corresponding debt completely disappears, which *ceteris paribus* leads to a higher capital stock. The reduction in precautionary savings that results from a better provision of risk-sharing opportunities cannot compensate for this. The difference in the long-run capital stock between the three tax systems is essentially due to the differences in net labor 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 0.10 percent.

With capital becoming relatively abundant, the interest rate falls by around 0.14 percentage points and at the same time the wage rate increases by more than 0.50 percent in all three reform scenarios. Income tax revenues are boosted owing to an increase in capital and labor income, so that the average income tax rate can decline.

4.2. Transitional dynamics

The macroeconomic transition path generated by the policy reforms is illustrated by Fig. 5. At the time the reform hits, effective employment drops by 1.05% to 1.18%, depending on the type of policy. In the immediately following period labor supply reaches its maximum reduction at 1.98% (CT), 1.91% (GT), and 1.54% (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 labor supply starts to rise. In the long-run this leads to higher levels of labor 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 labor 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 labor 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 the 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?

Fig. 5. Transitional changes.

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 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

Fig. 6. Ex-ante welfare changes by cohort.

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 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 $t = 0$).¹²

4.3.1. The impact on welfare of different generations

In Fig. 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 SL 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.

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 student 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 labor income tax. The welfare losses are largest for the CT reform, as the comprehensive labor tax generates a substantial amount of redistribution from unskilled (mostly poor) to skilled (mostly rich) individuals. This regressive redistribution is minimized under the DT system, which is why it creates the smallest welfare losses for existing generations.¹³ Students are hurt also, but to a lesser extent the younger they are, as the student loan they have already accumulated is smaller and they can profit more from the new educational financing scheme. 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.

4.3.2. A closer look at long-run welfare

Fig. 6 revealed that moving to any of the three income dependent educational financing systems has the potential to increase *ex-ante* long-run welfare. Nevertheless, the magnitude of the welfare gains differs quite a bit across the three scenarios. To understand where these differences come from, we want to switch perspectives for a moment and take a look at the *ex-post* welfare impact by talent for education θ in the steady state. Taking this perspective informs us about the extent to which *ex-ante* welfare effects can be explained by the redistributive properties of the three educational financing systems. Our concept of welfare is again consumption compensating variation, meaning that we calculate the percentage change in consumption that an individual would have to receive in order to be equally well off as in the initial steady state. The negative of these percentage changes are shown in Fig. 7.

The figure reveals the varying degrees of redistribution between individuals of different educational ability inherent in the three educational financing systems. As the CT system holds everyone liable for financing the cost of education, individuals who do not participate in tertiary education at all (those with a low θ) are substantially worse off in such an environment (solid line). On the other hand, those individuals who do pursue a degree experience sizable welfare gains. This regressive redistribution is not present in the GT and DT systems, under which low- θ individuals are actually experiencing welfare gains that follow from increases in long-run wages. While the GT system still generates redistribution from

¹² For more details on how the transfer levels are calculated, see Heijdra et al. (2014).

¹³ Note that since welfare is measured from an *ex-ante* perspective also for current generations, redistribution from the poor to the rich does create welfare losses.

Fig. 7. Ex-post welfare change by talent for education in the steady state.

individuals with a lower to those with a higher level of education, the welfare effects are much more evenly distributed over all θ types in the DT system. Overall, we find that both graduate and degree taxes can increase ex-post welfare of all individuals in the long-run, regardless of their talent for education.

4.3.3. Aggregating welfare effects across generations

The previous 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 Fig. 6, we calculate the present value of the negative of all compensating 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.¹⁴

As reported in the final row “Total” of Table 6, the comprehensive tax system creates an aggregate welfare gain of 0.13%, while for the GT and the DT system the welfare gains are larger at 0.33% and 0.26%, respectively. This implies that everybody can be made better off (in an ex-ante sense) if the reform from SL to any income dependent financing scheme takes place and generations are appropriately compensated.

4.3.4. Decomposition of aggregate welfare effects

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

- (±) *Redistribution*: A tax-based educational financing system generates two types of redistribution. First, as payments depend on labor earnings the risk of an investment in education can be shared which improves the welfare of risk-averse educated workers (risk sharing). Second, depending on how the tax base is chosen there may be transfers from the low to the highly educated, which reduces welfare from an ex-ante perspective (regressive redistribution).
- (−) *Work incentives*: With an educational labor tax individuals can influence their contributions to the system by working fewer hours. This moral hazard effect creates a distortion of labor supply which negatively impacts aggregate welfare.
- (±) *Education incentives*: As shown above, all three reforms lead to an increase in average educational attainment. If there was underinvestment in education under the SL system and the tax-based system (partly) corrects the distortion then an increase in the number of students is 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.

¹⁴ 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.

Table 6
Decomposition of aggregate welfare changes.

	CT	GT	DT
Redistribution effect	−0.13%	0.19%	0.24%
Work-incentive effect	−0.25%	−0.32%	−0.32%
Educational-incentive effect	0.46%	0.43%	0.30%
General equilibrium effect	0.04%	0.03%	0.03%
Total	0.13%	0.33%	0.26%

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 student loans.¹⁵

To isolate the effects of 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 labor tax as being lump-sum to avoid labor supply distortions, while in fact it is related to their gross labor income. The aggregate welfare effects of moving from student 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 −0.13% of aggregate consumption, as regressive redistribution from the low to the high skilled outweighs the gains from risk-sharing among the college-educated. 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 0.19%. 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 0.24% 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 $-0.13\% - 0.24\% = -0.37\%$.

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 labor income. As a consequence the tax not only has an income effect but also a substitution effect which distorts the labor 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. In order to understand these numbers, recall that the labor supply decision of individuals in our model is not only determined by the tax rate they pay, but also by the prospective return from learning-by-doing. Individuals with a high learning-by-doing parameter are less responsive to changes in the instantaneous price of labor through taxes. In other words, we expect them to have a relatively low labor supply elasticity. At the same time, these individuals tend to have a high income level, since they have accumulated a lot of experience in the past and are generally highly educated (recall the positive correlation between γ and θ). Hence, average labor supply elasticities in our model are likely to decline with income which means that taxing high-income individuals is the least distorting. Given this feature of the model it becomes immediately clear that using a progressive tax to finance grants to students creates the smallest amount of labor supply distortions. The progressive tax system systematically allocates higher tax rates to workers with a higher labor productivity. The GT and the DT system only imperfectly create such an allocation by conditioning (proportional) tax rates on educational attainment. However, even within the group of highly educated individuals there might be individuals experiencing a bad run in the labor market. Hence, the distortions created from these systems are larger than from comprehensive progressive taxes.¹⁶

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 effects from education incentives are sizable in any of the three reform scenarios and largest under the CT system that creates the strongest expansion of educational activity. This result indicates that under the initial SL system in combination with the progressive tax, there was substantial underinvestment in education. By incentivizing individuals to consistently choose higher education degrees, the income-contingent educational financing systems counteract this underinvestment. Yet, one should note that the *increase* in the welfare gain from the education incentive effect is 13 percentage points when moving from DT to GT but only 3 percentage points from GT to CT in Table 6. Hence, it is likely that increasing education even further than under CT could have a negative effect on aggregate welfare.

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 largest under the CT reform because the interest rate decreases a bit more than in the other scenarios.

¹⁵ We only provide the welfare numbers for these simulations. Detailed simulation results are available upon request.

¹⁶ To substantiate our argument we ran a simulation in which we assumed the comprehensive educational financing tax to also be proportional. In this scenario, the work-incentive effect of the CT system was −0.30%.

Table 7
Education distribution and tax rates in the hybrid educational financing system.

	Hybrid			Hybrid
	Share	τ^e		
0 years	9.45%p	−1.94%	Redistribution effect	0.55%
2 years	−11.80%p	3.78%	Work-incentive effect	−0.31%
4 years	−13.76%p	3.92%	Educational-incentive effect	0.19%
6 years	16.11%p	4.05%	General equilibrium effect	0.02%
			Total	0.45%

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 in all three proposed income-contingent educational financing systems. The CT performs the poorest of the three systems, because regressive redistribution from the unskilled to the skilled negatively impacts on aggregate welfare.

4.4. A hybrid system

The previous section clearly illustrated that there is a trade-off between facilitating risk-sharing and providing incentives for greater investment in education on the one hand, and regressive redistribution and labor supply distortions on the other hand. Lastly we investigate whether we can achieve a greater aggregate welfare gain by combining features of the different tax-based educational financing systems. In order to do so we look at hybrid systems in which a fraction λ_G of each transfer to a student is financed by a graduate tax and a share λ_D by a degree tax. The remaining share $1 - \lambda_G - \lambda_D$ is then collected through a proportional tax on the whole work force. We run simulations with many different combinations of λ_G and λ_D and pick the one that maximizes aggregate welfare.

If we restrict all shares to be between zero and one, then the best hybrid system is one financed purely by graduate taxes so that $\lambda_G = 1$ and $\lambda_D = 0$. We also consider the possibility that λ_G and λ_D are not restricted in any way, so that paying subsidies to certain education groups is possible. The best hybrid system then features $\lambda_G = 2.47$ and $\lambda_D = 0.17$. The resulting educational tax rates and the changes in the education distribution are given in the left-hand panel of Table 7. Since $1 - \lambda_G - \lambda_D$ is negative, individuals who choose not to pursue tertiary education actually receive a subsidy amounting to roughly 2 percent of their wage income. Those with a degree, on the other hand, pay taxes that range from 3.78% for individuals with two years of education to 4.05% for individuals with six. The result is a polarization of the workforce in terms of educational attainment, in the sense that both the share of workers without any education and the share with the highest possible attainment increase relative to the fraction of individuals with intermediate levels of education.

The right-hand panel of Table 7 shows the aggregate welfare effects associated with the unrestricted hybrid educational financing system. Aggregate welfare increases by 0.45% in terms of consumption compensating variation, which is more than 0.10 percentage points larger than the maximum welfare gain from each of the educational financing systems studied above (recall that it was highest for GT with 0.33%). This is largely driven by a positive redistribution effect, as the system not only provides risk-sharing among college graduates but also a redistribution from the educated to the uneducated. The work-incentive effect is quite similar to the previous simulations. The polarization of the work force in terms of educational attainment leads to an education incentive effect that is much smaller in size than in any of the other systems. Finally, the general equilibrium effect is again positive but small.

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 student loans or transfers. Individuals are heterogeneous in their talent for education and ability to learn on the job and face uninsurable idiosyncratic labor productivity risk during their working career.

We calibrate the model to the United States student loan system and subsequently consider three possible reforms, all involving labor taxation. The first is a Comprehensive Tax (CT) system under which transfers to students are financed by an additional progressive labor 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 gain because the positive effect of increased educational attainment outweighs the losses caused by regressive redistribution and labor supply distortions. 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. Aggregate welfare is higher than under CT because the system allows for risk-sharing among college graduates while limiting the degree of regressive redistribution. The third reform is a Degree Tax (DT) which is similar to the GT system except that the educational tax is conditioned on the highest degree attained by the worker. While such a system provides the strongest risk-sharing benefits, it performs less well in terms of educational incentives so that its aggregate welfare impact is in between the other two.

In an online appendix we provide two sensitivity checks for these results. First, we study the case in which only future generations participate in a tax-based educational financing system while the government uses public debt to finance short-term budget shortages. This ensures that most of the current generations are better off under the reform, but the aggregate welfare benefits are much smaller because public debt crowds out private capital. In the second scenario we relax the assumption of perfect substitutability of different types of labor and distinguish between college and high-school labor in the production function. The college wage premium then responds to changes in the number of college graduates, which dampens the positive effect of each reform on educational attainment. In both scenarios, however, the ranking of the different educational financing systems in terms of aggregate welfare remains unchanged.

Finally, we investigate whether a hybrid system of graduate and degree taxes paired with a proportional tax on the total work force can do better in terms of aggregate welfare. If the share of expenses financed by any of the three taxes is not restricted in any way then the best hybrid system features a subsidy to individuals who only hold a high school degree. By doing so, it maximizes the benefits from redistribution and risk-sharing so that the aggregate welfare gain is even larger than under a pure graduate tax.

Overall we conclude that it might be advisable for policy makers in developed countries to consider introducing income-contingent educational financing systems to finance transfers to students. Such systems provides valuable risk-sharing among college graduates and may correct for distortions in college choices created by progressive taxation. However, as our analysis of the transitional dynamics shows, appropriate compensation of individuals who have already accumulated student loans is crucial in order to prevent them from paying the same bill twice.

Our study leaves room for future research. First, it might 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. Second, 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 individual behavior.

Appendix A. Supplementary material

Supplementary material related to this article can be found online at <http://dx.doi.org/10.1016/j.red.2017.02.006>.

References

- Abbott, B., Gallipoli, G., Meghir, C., Violante, G.L., 2016. Education Policy and Intergenerational Transfers in Equilibrium. Discussion Paper 1887R, Cowles Foundation, New Haven.
- Aiyagari, S.R., 1994. Uninsured idiosyncratic risk and aggregate saving. *Journal of Political Economy* 109, 659–684.
- Akyol, A., Athreya, K., 2005. Risky higher education and subsidies. *Journal of Economic Dynamics and Control* 29, 979–1023.
- Avery, C., Turner, S., 2012. Students loans: do college students borrow too much – or not enough? *The Journal of Economic Perspectives* 26, 165–192.
- Backus, D.K., Routledge, B.R., Zin, S.E., 2004. Exotic preferences for macroeconomists. *NBER Macroeconomics Annual* 19, 319–390.
- Bewley, T., 1977. The permanent income hypothesis: a theoretical formulation. *Journal of Economic Theory* 16, 252–292.
- Cecchetti, S.G., Lam, P.-S., Mark, N.C., 2000. Asset pricing with distorted beliefs: are equity returns too good to be true? *The American Economic Review* 90, 787–805.
- Cigno, A., Luporini, A., 2009. Scholarships or student loans? Subsidizing higher education in the presence of moral hazard. *Journal of Public Economic Theory* 11, 55–87.
- Del Rey, E., Racionero, M., 2010. Financing schemes for higher education. *European Journal of Political Economy* 26, 104–113.
- Eckwert, B., Zilcha, I., 2012. Private investment in higher education: comparing alternative funding schemes. *Economica* 79, 76–96.
- Epstein, L.G., Zin, S.E., 1991. Substitution, risk aversion, and the temporal behavior of consumption and asset returns: an empirical analysis. *Journal of Political Economy* 99, 263–286.
- Fehr, H., Kindermann, F., 2015. Taxing capital along the transition – not a bad idea after all? *Journal of Economic Dynamics and Control* 51, 64–77.
- Feldstein, M.S., 1969. The effects of taxation on risk taking. *Journal of Political Economy* 77, 755–764.
- Friedman, M., 1962. *Capitalism and Freedom*. University of Chicago Press, Chicago, IL.
- García-Peñalosa, C., Wälde, K., 2000. Efficiency and equity effects of subsidies to higher education. *Oxford Economic Papers* 52, 702–722.
- Guner, N., Lopez-Daneri, M., Ventura, G., 2014. Heterogeneity and Government Revenues: Higher Taxes at the Top? Discussion Paper 10071, CEPR.
- Güvenen, F., Karahan, F., Ozcan, S., Song, J., 2015. What do Data on Millions of U.S. Workers Reveal About Life-Cycle Earnings Risk? Working Paper 20913, NBER, Cambridge.
- Heathcote, J., Perri, F., Violante, G.L., 2010. Unequal we stand: an empirical analysis of economic inequality in the United States, 1967–2006. *Review of Economic Dynamics* 13, 15–51.
- Heathcote, J., Storesletten, K., Violante, G.L., 2014. Optimal Tax Progressivity: An Analytical Framework. Working Paper 19899, NBER, Cambridge.
- Heckman, J.J., Lochner, L., Todd, P., 2008. Earnings functions and rates of return. *Journal of Human Capital* 2, 1–31.
- Heijdra, B.J., Kindermann, F., Reijnders, L.S.M., 2014. Life in Shackles? The Quantitative Implications of Reforming the Educational Loan System. Working Paper 5013, CESifo, Munich.
- Heijdra, B.J., Reijnders, L.S.M., 2016. Human capital accumulation and the macroeconomy in an ageing society. *De Economist* 164, 297–334.
- Huggett, M., 1993. The risk-free rate in heterogeneous-agent incomplete-insurance economies. *Journal of Economic Dynamics and Control* 17, 953–969.
- Huggett, M., 1997. The one-sector growth model with idiosyncratic shocks: steady states and dynamics. *Journal of Monetary Economics* 39, 385–403.
- İmrohoroglu, A., Kitao, S., 2009. Labor supply elasticity and social security reform. *Journal of Public Economics* 93, 867–878.
- Ionescu, F., 2009. The federal student loan program: quantitative implications for college enrollment and default rates. *Review of Economic Dynamics* 12, 205–231.
- Jacobs, B., van Wijnbergen, S., 2007. Capital-market failure, adverse selection, and equity financing of higher education. *FinanzArchiv* 63, 1–32.
- Kindermann, F., Krueger, D., 2014. High Marginal Tax Rates on the Top 1%? Lessons from a Life Cycle Model with Idiosyncratic Income Risk. Working Paper 20601, NBER, Cambridge.

- King, R.G., Plosser, C.I., Rebelo, S., 2002. Production, growth and business cycles: technical appendix. *Computational Economics* 20, 87–116.
- Krueger, D., Ludwig, A., 2013. Optimal progressive labor income taxation and education subsidies when education decisions and intergenerational transfers are endogenous. *The American Economic Review: Papers and Proceedings* 103, 496–501.
- Kuhn, M., Ríos-Rull, J.-V., 2015. 2013 Update on the U.S. Earnings, Income, and Wealth Distributional Facts: A View From Macroeconomics. Working paper, University of Bonn.
- Lochner, L., Monge-Naranjo, A., 2011. The nature of credit constraints and human capital. *The American Economic Review* 101, 2487–2529.
- Lochner, L., Monge-Naranjo, A., 2015. Student Loans and Repayment: Theory, Evidence and Policy. Working Paper 20849, NBER, Cambridge.
- Low, H.W., 2005. Self-insurance in a life-cycle model of labour supply and savings. *Review of Economic Dynamics* 8, 945–975.
- Mankiw, N.G., Romer, D., Weil, D.N., 1992. A contribution to the empirics of economic growth. *The Quarterly Journal of Economics* 107, 407–437.