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246

Fabian Kindermann

**Public versus Private Education
with Risky Human Capital**

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Public versus Private Education with Risky Human Capital[‡]

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November 2009

Abstract

This paper studies the long-run macroeconomic, distributional and welfare effects of tuition policy and student loans. We therefore form a rich model of risky human capital investment based on the seminal work of Heckman, Lochner and Taber (1998). We extend their original model by variable labor supply, borrowing constraints, idiosyncratic wage risk, uncertain life-span, and multiple schooling decisions. This allows us to build a direct link between students and their parents and make the initial distribution of people over different socio-economic backgrounds endogenous.

Our simulation indicate that privatization of tertiary education comes with a vast reduction in the number of students, an increase in the college wage premium and long-run welfare losses of around 5 percent. Surprisingly, we find that from privatization of tertiary education, students are better off compared to workers from other educational classes, since the college wage premium nearly doubles. In addition, our model predicts that income contingent loans on which students don't have to pay interest, improve the college enrolment situation for agents from all kinds of backgrounds.

JEL Classification: I22, J24, H52

Keywords: public vs. private education, schooling choice, human capital investment, idiosyncratic uncertainty

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1 Introduction

Since the decision of the Federal Constitutional Court in 2005, which paved the way for tuition fees in Germany, higher educational finance has become more important than ever. Whether to make students pay for their tertiary education or not was a popular topic in the public dialogue. On the one hand, defenders of the existing public higher education system argued with the existence of external effects, liquidity constraints and uninsurable tertiary education risk, see Wigger (2004) or Kupferschmidt and Wigger (2006) for a discussion. On the other hand, advocates of tuition fees refer to the negative distributional consequences of educational subsidies, see Borgloh, Kupferschmidt and Wigger (2008).

In the theoretical literature, higher education subsidies and the optimal design of student loans have received some attention. García-Peñalosa and Wälde (2000), for example, study optimal educational finance in a model of endogenous schooling choice. As education in their model is a risky investment, they argue for tuition financed education with income contingent governmental student loans. They find that a graduate tax system, where successful university graduates pay for the burden arising from unsuccessful students, is to be favored, because there is no ex-post redistribution from the unskilled to the skilled. In addition, Wigger and von Weizäcker (2001) show in a one-period model that government should insure educational risk completely in a first-best setup. If, however, adverse selection and moral hazard problems arise, a success dependent tuition fee system should be optimal. Caucutt and Kumar (2003) explore in a two-period OLG setup the effects of higher education subsidies on college enrolment, welfare and efficiency. Their analysis indicates that a policy to make enrollment decisions independent of ability comes with an inefficient use of educational resources and only produces small welfare gains. Maximizing the number of students via a subsidy system enforces the problem of inefficient use and does not generate any positive welfare effects at all.

The model of Heckman, Lochner and Taber (1998) often acts as a basis for numerical analyses of tuition and higher education subsidies. This model originally was designed to analyze the sources of wage inequality trends in the US in the after war period. The model features both schooling choice and on-the-job human capital investment. It allows for heterogeneity in abilities and general equilibrium price reactions. The main finding of their seminal work is that changes in wage differentials in the US can only be explained by skill-biased technical change. These results are confirmed by Abraham (2008) and Keane and Roemer (2009) in even richer frameworks. de La Croix and Docquier (2007) use an 8 period endogenous human capital investment model in order to identify the sources of the evolution of skill premia in France and the US. In the US, higher educational costs damped the rise in educational attainment and contributed to higher wage differentials between the unskilled and

the skilled. Hence, skill biased technical change is essential to understanding rising school attendance. In contrast, an expansionary educational policy boosted the supply of skills and kept the skill premium low in France. However, skill biased technical change only played a minor role in explaining wage differentials.

In a following analysis, Heckman, Lochner and Taber (1999) use their estimated general equilibrium model to analyze the effects of tax reform and educational subsidy policy. They state that a 500\$ revenue neutral increase in tuition subsidies leads to a 5.3 percent increase in the number of students in a partial equilibrium model. However, incorporating the general equilibrium effects, the effect shrinks to 0.46 percent. Hence, analyzing tuition policy in general equilibrium seems absolutely necessary. Akyol and Athreya (2005) study a model of risky human capital formation with infinitely lived consumers who make a schooling choice in the first period of life. They find that higher education subsidies increase the number of students and the wage of the lower skilled, which in turn narrows the skill premium. In addition, as there is a certain chance of college failure, i.e. people might drop back to the class of lower skilled workers, the risk of college education shrinks.

Garriga and Keightley (2007) form a very detailed model of risky college human capital formation. Early drop-outs and resulting partial education are possible and endogenous. In addition, the effort put on college education influences the outcome. The authors study the effect of tuition subsidies, grant subsidies and loan limit restrictions. They find that broad band tuition policies and grants increase enrolment, but mainly that of lower ability students that might drop-out early or need a longer time for their studies. Merit based subsidies, on the other hand, counter-act this adverse selection problem, however at the price of lower aggregate enrolment rates. Gallipoli, Meghir and Violante (2008) analyze the long-run effects of different educational policies on the distribution of education and earnings in a model with endogenous labor supply, idiosyncratic income risk and schooling choice. Their model features three different schooling types: lower than high-school, high-school and college. They estimate dynamic income processes, the distribution of ability and a transition process for ability from US data. They finally introduce tuition subsidies which are conditional on financial resources. Those are successful in increasing enrolment rates and reducing inequality in partial equilibrium. In general equilibrium, however, subsidies mainly act on more able but liquidity constraint agents, so that the education of less able might be crowded out and inequality rises. Ionescu (2009) forms an OLG model of both schooling choice and human capital investment without riskiness in human capital investment. Students can borrow on student loans during the time of their college education, where the interest rates on those credits is uncertain. She finds that learning ability and initial human capital drive the college enrolment decision, whereas parental wealth is not very important. She then analyzes different repayment schemes for student loans. Allowing students to log-

in their interest rates or switch repayment plans increases enrolment in this model, whereas relaxed loan eligibility requirements have little effects. Hence, subsidizing repayment rather than increasing eligibility is to be favored.

The OLG model of endogenous schooling choice and on-the-job human capital accumulation we use to quantify the long-run effects of higher education financing is also based on the work of Heckman et al. (1998). We extend their original model in various directions. Beneath modeling variable labor supply, borrowing constraints, idiosyncratic wage risk, and uncertain life-span, we consider multiple schooling decisions in the sense of Gallipoli et al. (2008). This allows us to build a direct link between students and their parents. On the one hand, students' schooling choice depends on the educational background of their parents. On the other hand, the final distribution of agents over educational levels is determined by the schooling choice at the beginning of the life cycle. This leads to different intra-cohort distributional effects compared to conventional models that fix the initial distribution over ability and educational background once and for all.

In contrast to Gallipoli et al. (2008), we let agents still invest into human capital on-the-job, where this investment is of risky type. Furthermore, we make the tertiary education schooling choice, i.e. the college enrolment decision, a risky investment. We assume, in line with García-Peñalosa and Wälde (2000) that, at the end of their university phase, students have to take a final exam, which they only pass with a certain probability. Finally, a detailed modeling of the government sector with taxes on consumption, labor and interest income, governmental debt, educational spending and a pay-as-you-go Bismarckian pension system complements our model.

We calibrate our model to the German economy in 2007 and estimate production parameters for the production of human capital on-the-job and an autoregressive process for the evolution of labor income shocks. We then simulate a privatization of the current publicly financed education system as well as the introduction of income contingent student loans. Our simulations indicate that privatization of tertiary education comes with a vast reduction in the number of students, an increase in the college wage premium and long-run welfare losses of around 5 percent of initial resources. In addition, if we account for the fact that the initial distribution of households across socio-economic backgrounds is endogenous, schooling choice behavior is altered significantly. Surprisingly, we find that from privatization of tertiary education, students are better off compared to workers from other educational classes, since the college wage premium nearly doubles and the decline in consumption tax rates can't offset the decrease in labor income for lower educated households. This result is in contrast to common theoretical models of schooling, where wages usually are fixed, see e.g. García-Peñalosa and Wälde (2000). Finally, our model predicts that the declining college enrolment rates and welfare losses from tertiary education privatization can't

be offset by an income contingent student loan system, which shifts the burden of tuition to later periods in life and provides insurance against college failure.

In terms of income contingent loans that are given on top of the current publicly financed education system, two major points arise. First, income contingent loans might reduce enrolment rates for people with richer socio-economic backgrounds due to the reduction in the college wage premium. Second, loans on which students don't have to pay interest, i.e. loans that act like a tertiary education subsidy, improve the college enrolment situation for agents from all kinds of socio-economic backgrounds. With income revenues increasing with this reforms, the burdens arising from income contingency are carried to a large part by successful college graduates and, hence, the consumption tax rate increases only slightly. Consequently, the common argument that mainly people with lower education carry the burden of subsidies to higher education does not hold in this case.

The remainder of the paper is organized as follows. Section 2 gives a detailed insight into the model. Section 3 describes our parameter estimations and calibration methodology. Simulation results are presented in Section 4. Section 5 offers some concluding remarks.

2 The model economy

2.1 Demographics and intracohort heterogeneity

We consider an economy populated by overlapping generations of individuals, which may live up to a maximum possible lifespan of J periods. At the beginning of each period, a new generation is born where we assume a population growth rate of n . Since individuals face lifespan uncertainty, $\psi_j < 1$ denotes the time-invariant conditional survival probability from age $j - 1$ to age j with $\psi_{J+1} = 0$.

Our model is solved recursively. Consequently, an age- j agent faces the state vector

$$z_j = (s_j, \varsigma_j, s_p, a_j, ep_j, h_j, \eta_j) \quad (1)$$

where $s_j \in \mathcal{S} = \{1, \dots, S\}$ and $s_p \in \mathcal{S}$ are agent's current schooling level at age j and time-invariant socio-economic background, i.e. parent's schooling level. $\varsigma_j \in \mathcal{I} = \{0, 1\}$ indicates whether the individual is still in education or already has fully joined the labor force, see below. Finally, $a_j \in A = [0, \infty)$, $ep_j \in P = [0, \overline{ep}]$ and $h_j \in H = [0, \infty)$ denote assets held at the beginning of age j , accumulated earning points for public pension claims and stock of human capital,¹ and $\eta_j \in \mathcal{E} = [0, \infty)$ is a shock to household's productivity.

¹ In the following, human capital and labor productivity are used synonymously.

The productivity shock is assumed to follow a first-order Markov process described in more detail below. For the sake of simplification, we let $\mathcal{C} = A \times P \times H \times \mathcal{E}$ the set of continuous states.

According to the initial distribution at age $j = 1$, mortality rates, population growth, the Markov process and optimal household decisions, each age- j cohort is fragmented into sub-groups $\xi(z_j)$. Let $X(z_j)$ be the corresponding cumulated measure to $\xi(z_j)$. Hence,

$$\int_{\mathcal{S} \times \mathcal{I} \times \mathcal{S} \times \mathcal{H} \times \mathcal{E}} dX(z_1) = 1 \quad \text{with} \quad z_1 = (s_1, \varsigma_1, s_p, 0, 0, h_1, \eta_1) \quad (2)$$

must hold, since we have normalized the cohort size of newborns to be unity.

By assumption, parents are of age j_p when their children enter the economically relevant age. Accordingly, the initial distribution of agents across socio-economic backgrounds s_p depends on the number of agents of different schooling types s_{j_p} at age j_p . For example, assume that there are only two types of education, i.e. $S = 2$, and at age j_p 60 percent of agents hold a high-school and 40 percent a college degree. Hence, in the newborn cohort, there will be 60 percent of agent with socio-economic background $s_p = 1$ (i.e. high school) and 40 percent with $s_p = 2$.

In the following, we will omit the state indices z_j for every variable whenever possible. Agents are then only distinguished according to their age j .

2.2 The household decision problem

The decision about assets, leisure and on-the-job training

Our model assumes a preference structure that is represented by a time-separable, nested CES utility function. Extending the model of Heckman et al. (1998) by variable labor supply, we assume an agent at age j to solve the optimization problem

$$V(z_j) = \max_{c_j, \ell_j, e_j} \left\{ u(c_j, \ell_j) + \delta \psi_{j+1} E \left[V(z_{j+1})^{1-\frac{1}{\gamma}} \right] \right\}^{\frac{1}{1-\frac{1}{\gamma}}}, \quad (3)$$

where c_j , ℓ_j and e_j indicate consumption, leisure time and on-the-job human capital investment at age j , respectively, and γ is the intertemporal rate of substitution between consumption in different years.² The instantaneous utility function is defined as

$$u(c_j, \ell_j) = \left[(c_j)^{1-\frac{1}{\rho}} + \alpha (\ell_j)^{1-\frac{1}{\rho}} \right]^{\frac{1-\frac{1}{\gamma}}{1-\frac{1}{\rho}}}, \quad (4)$$

² We use this monotonic transformation of the regular CES utility function for computational reasons, as it guarantees utility to be bound from below by 0.

where ρ denotes the intratemporal elasticity of substitution between consumption and leisure at each age j while α is the age-independent leisure preference parameter.

Households maximize (3) subject to the budget constraint

$$a_{j+1} = a_j(1+r) + w_j + p_j - \tau \min[w_j; 2\bar{w}] - T[y_j^w, y_j^r] + b_j + \kappa_j - (1 + \tau_c)c_j \quad (5)$$

with $a_1 = a_{J+1} = 0$ and $a_j \geq 0$. In addition to interest income from savings ra_j , households receive gross labor income w_j during their working period as well as public pensions p_j during retirement. If they have fully joined the labor force, i.e. $\varsigma_j = 0$, agents can devote their overall time endowment of 1 to leisure consumption, on-the-job human capital investment and work. If still in education, they are not allowed to additionally invest into human capital on-the-job and have to devote a fixed fraction ϖ of their time endowment to their studies. Hence,

$$w_j = \begin{cases} w^s(1 - \ell_j - e_j)h_j\eta_j, & \text{if } \varsigma_j = 0 \\ w^s(1 - \varpi - \ell_j)h_j\eta_j, & \text{if } \varsigma_j = 1, \end{cases} \quad (6)$$

where w^s defines the wage rate for effective labor of schooling class s , h_j household's labor efficiency and η_j the current shock to labor income. At specific ages, households also receive accidental bequests b_j as well as inter vivos transfers κ_j . Contributions at a rate τ are paid to the public pension system up to a ceiling which amounts to the double of average income \bar{w} . Income taxes depend on taxable labor and capital income y_j^w and y_j^r and the tax schedule $T[\cdot, \cdot]$ which is explained below. Finally, the price of consumption goods c_j includes consumption taxes τ_c .

In order to manage their costs of living, children that are in education, i.e. $\varsigma_j = 1$, receive lump sum transfers κ_j which amount to a fixed fraction ζ of parents' income at j_p , i.e.

$$\kappa_j(z_j) = \zeta \int_{I \times S \times C} w_{j_p} dX(z_{j_p}), \quad \text{with } z_j = (\cdot, \cdot, s_p, \cdot, \cdot, \cdot, \cdot) \text{ and } z_{j_p} = (s_p, \cdot, \cdot, \cdot, \cdot, \cdot, \cdot). \quad (7)$$

Note that, if children are of socio-economic background s_p , their parents obviously have to be of schooling class $s_{j_p} = s_p$. As agents with higher educational degree usually have a higher income, the level of inter vivos transfers will rise with increasing socio-economic background. Finally, the necessary (negative) κ_{j_p} for the parent generations can be computed from the amount of transfers, cohort sizes and the fraction of children choosing a certain level of education.

Our model abstracts from private annuity markets. Consequently, private assets of all agents who died are aggregated and then distributed among all working age cohorts following an

age-dependent distribution scheme Γ_j , i.e.

$$b_j(z_j) = \frac{\Gamma_j}{(1+n)} \sum_{k=1}^J (1 - \psi_{k+1}) \int_{\mathcal{I} \times \mathcal{S} \times \mathcal{C}} q_{k+1}(z_k) dX(z_k) \quad \forall \quad j < j_r,$$

with $z_j = (\cdot, \cdot, s_p, \cdot, \cdot, \cdot, \cdot)$ and $z_k = (s_p, \cdot, \cdot, \cdot, \cdot, \cdot, \cdot)$, (8)

where $q_{k+1}(z_k) = (1+r)a_{k+1}(z_k)$. The distribution of bequests is computed in every period, where we assume that children always inherit assets of their parents' generation j_p . Since bequest can only be received during employment, we adjust this rule at the beginning and the end of the employment phase. In order to account for agents' socio-economic background, within each cohort, the distribution is computed such that households with background s_p receive assets from agents of schooling type $s_{j_p} = s_p$ of the parental generation. Among individuals of a cohort and socio-economic background, bequests are then distributed equally. As the more educated usually are the more wealthy, households with richer parents will receive more bequests than those with poorer socio-economic background.

Accumulated earning points of the pension system depend on the relative income position w_j/\bar{w} of the worker at working age $j < j_r$. Since the contribution ceiling is fixed at the double of average income \bar{w} , maximum earning points collected per year are 2. Therefore, earning points accumulate according to

$$ep_{j+1} = ep_j + \min[w_j/\bar{w}; 2], \quad (9)$$

where $ep_1 = 0$.

In addition to investing in capital, households can devote time to on-the-job human capital investment. Following Heckman et al. (1998) we assume that on-the-job training just needs time effort. Hence, human capital evolves according to

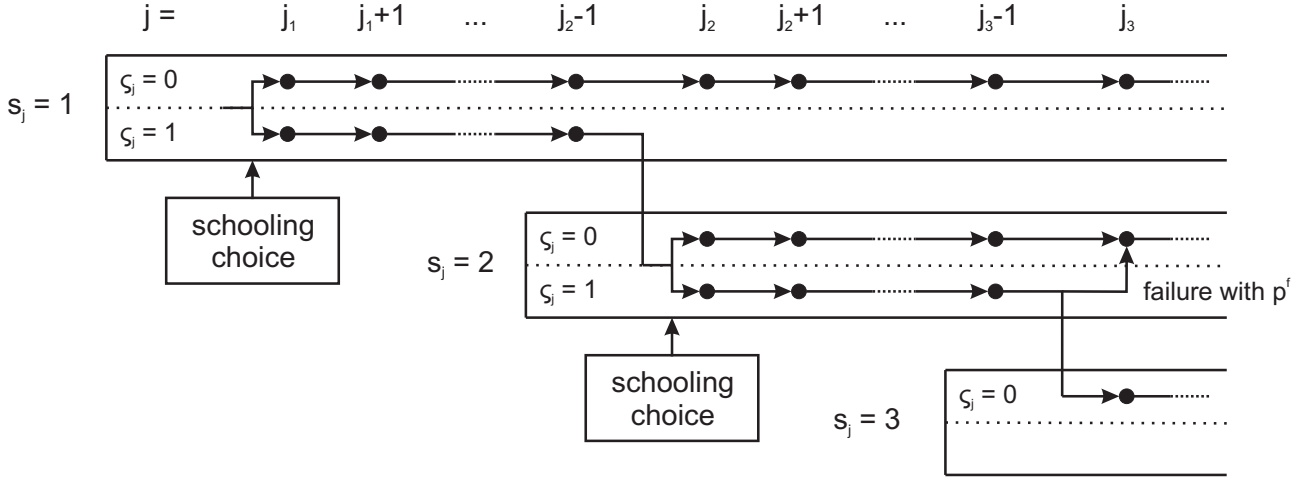
$$h_{j+1} = A_s e_j^{\nu_s} h_j^{\omega_s} + (1 - \delta_s^h) h_j, \quad (10)$$

where A_s is a production efficiency parameter, which indicates agent's ability to transform received education into labor productivity, ν_s and ω_s are elasticities with respect to time and human capital input and δ_s^h is depreciation on actual human capital.

Schooling choice and inter vivos transfers

Figure 1 shows the dynamics of schooling choice in our model, where we have assumed $S = 3$. Following Gallipoli et al. (2008) we assume several schooling choices that take place at different stages in the life-cycle. Lets denote by j_s the date of labor-market entry for an agent who has successfully completed schooling level s . At the beginning of the life-cycle at

Figure 1: Schooling choice and labor market entry



j_1 , all agents are of the same initial schooling type $s_1 = 1$. They now have to make their first educational decision. If they choose to drop out of the schooling system, i.e. $\varsigma_{j_1} = 0$, they enter the labor force and stay in schooling level 1 for the rest of their life. If they decide to stay in school, they remain in the schooling level 1 until the next date of labor market entry j_2 . At j_2 they again have to make a drop out or stay decision, etc.

We model the highest possible level of education, i.e. $s_j = 3$, as a risky investment. In this case there is a certain chance of failing. If households decide to participate in the highest educational program, they have to take a final exam in the year before labor market entry $j_3 - 1$, which they either pass or fail with the exogenous probability p^f . Hence, at the beginning of j_3 , a fraction p^f of the agents that are still in the schooling system remains in schooling class 2, but changes to $\varsigma_{j_3} = 0$, and a fraction $1 - p^f$ changes to $s_j = 3$. The expected college wage premium therefore can be defined as

$$\left(\frac{(1 - p^f)w_3 + p^f w_2}{w_2} - 1 \right) \times 100. \quad (11)$$

Note that there is no $\varsigma_j = 1$ agent in the highest educational class, as households in this class already have run through the maximum number of years of education.

In line with Taber (2002), agents decide about their drop-out via a comparison of utilities. An agent entering schooling level s at time j_s will stay in school, if

$$V_{j_s} \left(z_{j_s}^1 \right) + \varepsilon_{s,s_p} \geq V_{j_s} \left(z_{j_s}^0 \right), \quad (12)$$

where $V_{j_s} \left(z_{j_s}^1 \right)$ and $V_{j_s} \left(z_{j_s}^0 \right)$ are the utilities agent receives from staying in school or dropping out, i.e. $z_{j_s}^1 = (s, 1, s_p, \cdot, \cdot, \cdot, \cdot)$ and $z_{j_s}^0 = (s, 0, s_p, \cdot, \cdot, \cdot, \cdot)$, respectively, and ε_{s,s_p} measures

psychological costs of schooling. We hereby assume that ε_{s,s_p} is normally distributed with mean μ_{s,s_p} and variance σ^2 across every socio-economic background $s_p \in S$.

Assuming a large amount of people in every cohort, due to the law of large numbers,

$$P\left(\left\{V_{j_s}\left(z_{j_s}^1\right) + \varepsilon_{s,s_p} < V_{j_s}\left(z_{j_s}^0\right)\right\}\right) = \Phi_{\mu_{s,s_p}, \sigma^2}\left[V_{j_s}\left(z_{j_s}^0\right) - V_{j_s}\left(z_{j_s}^1\right)\right] \quad (13)$$

is the fraction of agents that decide to drop out of the schooling system at age j_s .

2.3 The production side

Firms in this economy use capital and labor of different types s to produce a single good according to a Cobb-Douglas production technology $Y = \varrho K^\epsilon L^{1-\epsilon}$ where Y, K and L are aggregate output, capital and labor, respectively, ϵ is capital's share in production, and ϱ defines a technology parameter. Labor is aggregated by a CES-technology

$$L = \left(\sum_{s=1}^S \lambda_s L_s^{1-\frac{1}{\chi}}\right)^{\frac{1}{1-\frac{1}{\chi}}}, \quad \text{with } \sum_{s=1}^S \lambda_s = 1. \quad (14)$$

Capital depreciates at a constant rate δ_k and firms have to pay corporate taxes

$$T_k = \tau_k \left[Y - \sum_{s=1}^S w^s L_s - \delta_k K \right], \quad (15)$$

where a corporate tax rate τ_k is applied to output net of labor costs and depreciation. Firms maximize profits renting capital and hiring labor from households, so that net marginal products equal r the interest rate for capital and w^s the wage rates for effective labor of different types.

2.4 The government sector

Our model distinguishes between the tax system and the pension system. In each period, government issues new debt nB_G and collects taxes from households and firms in order to finance general government expenditure G which is fixed per capita, educational spending G_s ³ on the different types of schooling systems which are held constant per student as well as interest payments on its debt, i.e.

$$nB_G + T_y + T_k + \tau_c C = G + \sum_{s=2}^S G_s + rB_G. \quad (16)$$

³ Note that, as the fraction of people who complete schooling type 1 is always 1 by definition, we can incorporate G_1 in general government expenditure G .

Revenues of income taxation are computed from

$$T_{y,t} = \sum_{j=1}^J \int_{\mathcal{S} \times \mathcal{I} \times \mathcal{S} \times \mathcal{C}} T \left[y_j^w(z_j), y_j^r(z_j) \right] dX(z_j) \quad (17)$$

and C defines aggregate consumption (see (24)).

We assume that contributions to public pensions are exempted from tax while benefits are fully taxed. Consequently, taxable labor income y_j^w is computed from gross labor income net of pension contributions, a flexible work related allowance $d_w(w_j)$, and – after retirement – public pensions. Interest income is taxed separately at a flat tax rate with a fixed allowance of d_r . Hence,

$$y_j^w = \max[w_j - \tau \min[w_j, 2\bar{w}] - d_w(w_j); 0] + p_j, \quad \text{and} \quad y_j^r = \max[ra_j - d_r; 0]. \quad (18)$$

Given taxable income, we apply the progressive tax code of 2005 in Germany to labor income and a flat tax τ_r to capital income, i.e. $T \left[y_j^w(z_j), y_j^r(z_j) \right] = (1 + \tau_z) \left[T05(y_j^w) + \tau_r y_j^r \right]$, where τ_z is a solidarity surcharge. This corresponds to the flat capital gains tax system recently introduced in Germany. The governmental budget is closed period-by-period by adjusting the consumption tax rate.

In each period, the pension system pays old-age benefits and collects payroll contributions from wage income below the contribution ceiling of $2\bar{w}$. Individual pension benefits p_j of a retiree at age $j \geq j_r$ in a specific year are computed from the product of her earning points ep_{j_r} she has accumulated at retirement and the actual pension amount (APA) per earning point

$$p_j = ep_{j_r} \times APA. \quad (19)$$

The budget of the pension system must be balanced periodically by adjusting the social security tax rate τ . Consequently, $\tau = \frac{PB}{PC}$, where

$$PB = \sum_{j=j_r}^J \int_{\mathcal{S} \times \mathcal{I} \times \mathcal{S} \times \mathcal{C}} p_j(z_j) dX_t(z_j), \quad \text{and} \quad (20)$$

$$PC = \sum_{j=1}^{j_r-1} \int_{\mathcal{S} \times \mathcal{I} \times \mathcal{S} \times \mathcal{C}} \min[w_j(z_j); 2\bar{w}] dX(z_j) \quad (21)$$

define aggregate pensions benefits and the contribution base.

2.5 Equilibrium conditions

Given the fiscal policy $\Psi = \{G, \{G_s\}_{s=2}^S, T[\cdot, \cdot], B_G, \tau_c, \tau_r, \tau_k, \tau\}$, a recursive equilibrium path is a set of value functions $\{V(z_j)\}_{j=1}^J$, household decision rules $\{c_j(z_j), \ell_j(z_j), e_j(z_j)\}_{j=1}^J$,

distributions of unintended bequest $\{b_j(z_j)\}_{j=1}^J$, a time-invariant measure of households $\{\xi(z_j)\}_{j=1}^J$ and relative prices of labor and capital $\{\{w^s\}_{s=1}^S, r\}$ so that the following conditions are satisfied:

1. Households' decision rules solve the household's decision problem (3) subject to the given constraints (5), (10) and (9).
2. Factor prices are competitive, i.e.

$$w^s = (1 - \epsilon) \varrho \left(\frac{K}{L} \right)^\epsilon \frac{\partial L}{\partial L_s}, \quad (22)$$

$$r = \epsilon \varrho \left(\frac{L}{K} \right)^{1-\epsilon} - \delta_k. \quad (23)$$

3. In the closed economy aggregation holds,

$$\begin{aligned} L_s &= \sum_{j=1}^J \int_{\mathcal{I} \times \mathcal{S} \times \mathcal{C}} w_j / w^s dX(z_j) \\ C &= \sum_{j=1}^J \int_{\mathcal{S} \times \mathcal{I} \times \mathcal{S} \times \mathcal{C}} c_j(z_j) dX(z_j), \end{aligned} \quad (24)$$

$$K = \sum_{j=1}^J \int_{\mathcal{S} \times \mathcal{I} \times \mathcal{S} \times \mathcal{C}} a_j(z_j) dX(z_j) - B_G, \quad (25)$$

while in the small open economy aggregate capital is derived from (23).

4. Unintended bequests satisfy

$$\begin{aligned} (1+n) \sum_{j=1}^{j_r-1} \int_{\mathcal{S} \times \mathcal{I} \times \mathcal{S} \times \mathcal{C}} b_j(z_j) dX(z_j) = \\ \sum_{j=1}^J \int_{\mathcal{S} \times \mathcal{I} \times \mathcal{S} \times \mathcal{C}} q_{j+1}(z_j) (1 - \psi_{j+1}) dX(z_j). \end{aligned} \quad (26)$$

5. The budgets of the government and the pension system are balanced.
6. The goods market clears, i.e.

$$\begin{aligned} Y &= C + (n + \delta_k)K + G + \sum_{s=2}^S G_s && \text{(closed economy)} \\ Y &= C + (n + \delta_k)K + G + \sum_{s=2}^S G_s + NX && \text{(open economy)} \end{aligned}$$

with NX as net exports.

2.6 The computational algorithm

Solving the individual household problem

In order to compute a solution of the complex household problem, we discretize the state space. The state of a household is determined by $z_j = (s_j, \varsigma_j, s_p, a_j, ep_j, h_j, \eta_j) \in \mathcal{S} \times \mathcal{I} \times \mathcal{S} \times A \times H \times P \times \mathcal{E}$ where $A = \{a^1, \dots, a^{n_A}\}$, $P = \{ep^1, \dots, ep^{n_P}\}$, $H = \{h^1, \dots, h^{n_H}\}$, and $\mathcal{E} = \{e_j^1, \dots, e_j^{n_E}\}$ are discrete sets. For all these possible states z_j we compute the optimal decision of households from (3). Since $u(c_j, \ell_j)$ is not differentiable in every (c_j, ℓ_j) and $V(z_{j+1})$ is only known in a discrete set of points $z_{j+1} \in \mathcal{S} \times \mathcal{I} \times \mathcal{S} \times A \times H \times P \times \mathcal{E}$, this maximization problem can not be solved analytically. Therefore we have to use the following numerical maximization and interpolation algorithms to compute households optimal decision:

1. Compute (3) in age J for all possible z_J . Notice that $V(z_{J+1}) = 0$ and households are not allowed to work anymore and they die for sure in the next period. Hence, they consume all their resources.
2. Find (3) for all possible z_j by using Powell's algorithm (Press et al., 1996, 406ff.). Since this algorithm requires a continuous function, we have to interpolate $V(z_{j+1})$. Having computed the data $V(z_{j+1})$ for all $z_{j+1} \in \mathcal{S} \times \mathcal{I} \times \mathcal{S} \times A \times H \times P \times \mathcal{E}$ in the last step, we can now find a function sp_{j+1} which satisfies the interpolation conditions

$$sp_{j+1}(a_{j+1}^k, ep_{j+1}^l, h_{j+1}^m) = EV(z_{j+1}) \quad (27)$$

for all $k = 1, \dots, n_A$, $l = 1, \dots, n_P$ and $m = 1, \dots, n_H$. In this paper we use multidimensional spline interpolation, see Habermann and Kindermann (2007).

The macroeconomic computational algorithm

Our simulations start from initial steady states which reflect the German macroeconomy and schooling system. The computation method follows the Gauss-Seidel procedure of Auerbach and Kotlikoff (1987). We start with a guess for aggregate variables, bequest distribution and policy parameters. Then we compute the factor prices and the individual decision rules and value functions. This involves a discretization of the state space which is explained in the section before. Next we obtain the distribution of households and aggregate assets, labor supply and consumption as well as the social security tax rate and the consumption tax rate that balances government's budget. This information allows us to update the initial guesses. The procedure is repeated until the initial guesses and the resulting values for capital, labor, bequests and endogenous taxes have sufficiently converged. Next we solve for

a new long-run equilibrium resulting from a change in educational policy and compare the results.

3 Calibration of the initial equilibrium

This section describes how we fit our model to German data. Parameters of the production function for human capital on-the-job and the autoregressive process for labor income shocks are estimated from German Socio-Economic Panel data (SOEP), a description of which can be found in Wagner et al. (2007). Finally, we calibrate the remaining parameters in order to match main macroeconomic variables observed in Germany in 2007.

The timing of the model is as follows: as each model period covers 1 year, agents start life at age 15 ($j = 1$), are forced to retire at age 61 ($j_r = 47$) and face a maximum possible life span of 100 years ($J = 85$). We assume three different educational classes: lower secondary, higher secondary and tertiary education. Ages of entry into the labor market are 15 ($j_1 = 1$), 20 ($j_2 = 6$) and 25 ($j_3 = 11$) respectively, i.e. every additional educational degree needs 5 additional years of studying.

3.1 Parameter estimation for on-the-job training

In order to estimate the parameters for on-the-job human capital formation and the autoregressive income process, we use inflated income data y_{its} of primary household earners from the German SOEP. Our unbalanced panel data covers full-time workers between ages 20 and 60 of the years 1984 to 2006 and was divided into different educational groups according to the International Standard Classification of Education (ISCED) of the UNESCO of 1997. In order to receive three groups, we merge levels 0 to 2 (primary and lower secondary education), levels 3 and 4 (higher secondary and post-secondary education) as well as levels 5 and 6 (tertiary education) to one group each. This approach leads us to a total of 81798 observations, where we have 11298, 54081 and 16419 observations in groups one to three, respectively.

Having extracted this data from the SOEP, we use a variant of the estimation technique proposed by Heckman et al. (1998). Specifically, we take the above household model and assume that there are no shocks to labor income, agents are not liquidity constraint and there is no leisure consumption. In order to make the model comparable to the above specification with leisure choice, we assume for the estimation process a maximum time endowment of 0.4, which amounts to a 40 hours workweek length, see Auerbach and Kotlikoff (1987). Fol-

lowing Taber (2002), we then approximate the German tax schedule of 2005 using a second order polynomial T_a .

In this simplified model setup, we can separate consumption choice from human capital investment decisions. Hence, an agent's utility maximizing amount of on-the-job-training can be calculated from

$$PVE(h_j, ep_j) = \max_{e_j} \left\{ (0.4 - e_j)h_j(1 - \tau) + p_j - T_a [(0.4 - e_j)h_j w^s(1 - \tau) + p_j] + \frac{PVE(h_{j+1}, ep_{j+1})}{1 + r(1 - \tau^r)} \right\}, \quad (28)$$

where h_j and ep_j evolve according to (10) and (9), respectively. As we use a partial equilibrium model for the estimation procedure, we normalize the interest rate $r = 0.05$ and set the wages per efficiency unit of all three types of labor to 1. Next, we fix the pension contribution rate at $\tau = 0.195$ and choose an actual pension amount which is close to the one predicted from our general equilibrium model. Our model extends the estimation model of Taber (2002) by explicitly accounting for a PAYG pension system. As a PAYG pension system prolongates the period of yield of human capital investment, it is essential to our estimation model and has a major influence on the estimated parameters. Unfortunately, due to the lack of data, we can't estimate ability parameters that depend on agent's educational background.

With the above model, we now estimate the parameters A_s, ν_s and ω_s in the following way via non-linear least squares. We first set depreciation rates δ_s exogenously, so that we obtain a good fit of the model to the data. Specifically, we assume no depreciation for the educational classes 1 and 2 in accordance with Heckman et al. (1998) and a slight depreciation of $\delta_3 = 0.005$ for class 3 in order to account for the falling labor efficiency at the end of the working life in this group, compare Figure 2. Next, we start with some initial guesses of parameters A_s, ν_s, ω_s and compute the age gross income profiles $\hat{y}_{ts} = (0.4 - e_j)h_j$ for every educational background resulting from the above model (28). We then form log-residual sum of squares

$$RSS = \sum_i \sum_t \sum_s (\log(y_{its}) - \log(\hat{y}_{ts}))^2. \quad (29)$$

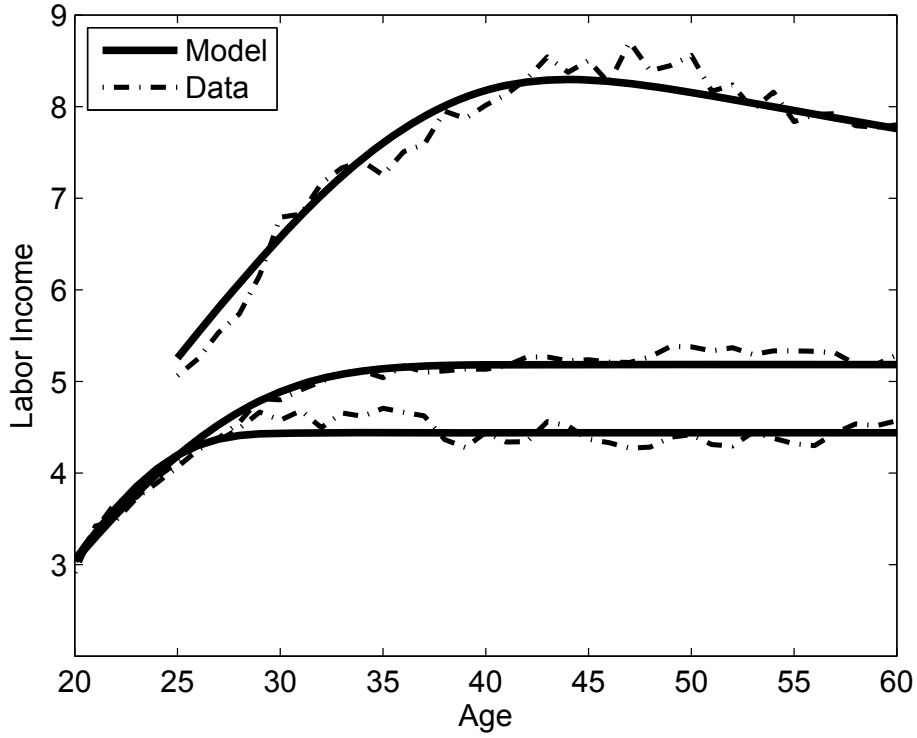
Our algorithm updates the parameter guesses in order to minimize RSS.

The resulting parameters and the corresponding Huber-White type standard errors (in parentheses) are reported in Table 1. Estimated gross income profiles and the respective means computed from the data are shown in Figure 2. Note that, due to the lack of data, we can only estimate the initial level of human capital at age 20 for the lowest educational group. Given the estimated parameters, this corresponds to a level of $h_1 = 7.5957$ at age 15, the age of labor market entry.

Table 1: Parameter estimates for human capital production functions

	Group 1	Group 2	Group 3
ability A_s	0.2469 (0.1940)	0.2874 (0.1311)	0.2628 (0.4897)
elasticity educational time ν_s	0.9838 (0.0065)	0.9448 (0.0035)	0.8784 (0.0132)
elasticity human capital ω_s	0.6723 (0.0052)	0.6138 (0.1874)	0.7294 (0.6340)
initial human capital h_{j_s}	9.8856 (0.0119)	10.4692 (0.0223)	16.7978 (0.1023)

Figure 2: Estimated and mean income profiles



3.2 Estimating the autoregressive income process

Taking log residuals of our above parameter estimation, we can now estimate labor income processes. Following Love (2007), we assume an autoregressive structure

$$\pi_j = \rho\pi_{j-1} + \epsilon_j \quad , \quad \epsilon_j \sim N(0, \sigma_\epsilon^2) \quad \text{and} \quad \pi_0 = 0. \quad (30)$$

Concerning our data, we therefore estimate the equation

$$\log(y_{its}) - \log(\hat{y}_{ts}) = v_i + \pi_{it} \quad (31)$$

with an individual effect $v_i \sim N(0, \sigma_v^2)$ separately for any of the three educational groups s by means of GLS, assuming π to follow an AR(1) process as in (30). This approach leads us to the parameter estimates shown in Table 2 (standard errors are again reported in parenthesis).

Table 2: Parameter estimates for individual productivity

	Group 1	Group 2	Group 3
AR(1) correlation ρ	0.6999 (0.0111)	0.7807 (0.0043)	0.7679 (0.0085)
persistent variance σ_v^2	0.0211 (0.0041)	0.0340 (0.0033)	0.0938 (0.0078)
transitory variance σ_ϵ^2	0.0635 (0.0044)	0.0728 (0.0036)	0.0801 (0.0069)

There are two things to notice. First, we find a strong AR(1) correlation of around 0.75 for the error term, which lies in the range of typical values for these types of models, see e.g. Love (2007). Second, except for group 3, we see a small persistent variance, which means that our groups are strongly homogeneous. In the highest educational group, however, there is a certain chance of climbing up into the area of extraordinary high salaries or failing and just getting a job for higher secondary earners. This makes the group somewhat more heterogeneous and explains a higher variance of the individual effect.

For computational reasons, we finally approximate the shock π by a first order discrete Markov process with two nodes using a discretization algorithm as described in Tauchen (1986).

3.3 The schooling choice

In order to calibrate the schooling choice, we set the standard deviation of psychological costs at $\sigma = 0.001121$, which is in line with the estimates reported in Heckman et al. (1998).⁴ Next we set the expected values μ_{is} like in Table 3.

With this specification we can replicate the observed schooling transition matrix in Germany. Table 4 reports on the left hand side the schooling choices of agents of different educational

⁴ We adjusted the standard deviation in order to account for the fact that we let agents make their schooling choice via a comparison of utilities, not present values of income.

Table 3: Expected values of psychological costs

$s_p \setminus s$	1	2
1	-0.0006076	-0.0009001
2	0.0003854	-0.0004903
3	0.0002924	0.0001601

backgrounds generated from our model. On the right hand side, we report estimates from Heineck and Riphahn (2009), who estimated transitional probabilities from German SOEP data.

Table 4: Decision matrix

Model				Data			
$s_p \setminus s$	1	2	3	$s_p \setminus s$	1	2	3
1	52.99	35.33	11.67	1	53.86	35.14	11.00
2	15.28	51.07	33.66	2	16.05	50.60	33.35
3	8.05	34.19	57.76	3	8.95	33.71	57.34

Finally, we fix the probability of failing at $p^f = 0.2$ which is in line with the fraction of college dropouts reported in AB (2008). This leads to a college premium of 49.2 percent, which corresponds to the tertiary education wage premium estimated for Germany in Strauss and de La Maisonneuve (2007).

3.4 Parameterizing the model

Table 5 reports the central remaining parameters of the model. The population growth rate is set at $n = 0.0$, since population growth is close to zero in Germany. The conditional survival probabilities ψ_j are computed from the year 2000 Life Tables for Germany reported in Bomsdorf (2003).

With respect to the preference parameters, we set the intertemporal elasticity of substitution γ at 0.5 and the intratemporal elasticity of substitution ρ at 0.6. This is within the range of commonly used values (see Auerbach and Kotlikoff, 1987, Fehr, 1999). Next, we calibrate the leisure preference parameter α in order to obtain an average labor time of 0.4 which corresponds to a 40 hours workweek length, see Auerbach and Kotlikoff (1987). In order to calibrate a realistic capital to output ratio, the discount factor is set at 0.981 which implies

Table 5: Parameter selection

Demographic parameters	Individual parameters	Technology parameters	Government parameters
$J = 85$	$\gamma = 0.5$	$\theta = 1.79$	$\tau_c = 0.17$
$j_r = 47$	$\rho = 0.6$	$\varepsilon = 0.35$	$B_G/Y = 0.6$
$j_1 = 1$	$\alpha = 0.5$	$\delta_k = 0.059$	$d_s = 1800$
$j_2 = 6$	$\delta = 0.981$	$\chi = 1.144$	$d(w_j) = 1200 + 0.04w_j$
$j_3 = 11$	$\omega = 0.4$	$\lambda_1 = 0.22$	$T(y^w, y^r)$ see text
$j_p = 28$	$\zeta = 0.16$	$\lambda_2 = 0.37$	APA see text
$n = 0.0$		$\lambda_3 = 0.40$	
ψ_j :Bomsdorf (2003)			

an annual discount rate of roughly 2 percent. Finally, we let the time students devote to studying be 40 hours per week, i.e. $\omega = 0.4$ and the fraction of income transmitted from parents to their studying children 16 percent, which corresponds to the figures reported in AB (2008).

With respect to technology parameters we specify the general factor productivity $\theta = 1.79$ in order to normalize labor income and set the capital share in production ε at 0.35. We set the elasticity of substitution between different types of labor at 1.441 which is equal to the estimate of Heckman et al. (1998) for US data and calibrate the input shares λ_s so that the marginal product of labor equals 1 for every type of education. The annual depreciation rate for capital is set at 5.9 percent, the annual APA value is chosen in order to derive a replacement rate of net income of 60 percent, which yields a realistic contribution rate for Germany. As already explained, the taxation of gross income (from labor, capital and pensions) is close to the current German income tax code. We apply the marginal tax rate schedule $T05$ which was introduced in 2005 to labor and pension income and a flat tax of 25 percent to interest payments. In addition, we consider a special allowance for labor income of $d(w_j)$ which combines a fixed amount of 1200 € and an additional deduction of 0.04 percent of labor income and a fixed allowance of 1800 € for capital income. Given taxable labor income y_j^w , the marginal tax rate rises linearly after the basic allowance of 7800 € from 15 percent to maximum of 42 percent when y_j passes 52.000 €. A solidarity surcharge of 5.5 percent is added to the total amount of taxes. In the initial long-run equilibrium, we assume a debt-to-output ratio of 60 percent, fix the consumption tax rate at 17 percent and compute G endogenously to balance the budget.

3.5 The initial equilibrium

Table 6 reports the calibrated benchmark equilibrium and the respective figures for Germany in 2007. As one can see, the initial equilibrium reflects quite realistically the current

Table 6: The initial equilibrium

	Model solution	Germany 2007
<i>Calibration targets</i>		
Capital-output ratio	3.0	2.9 ^a
Educational government spending (in % of GDP)	5.0	5.0 ^b
- secondary education	3.9	3.9 ^b
- tertiary education	1.1	1.1 ^b
Pension benefits (% of GDP)	12.1	11.5 ^a
Pension contribution rate (in %)	19.5	19.9 ^a
Tax revenues (in % of GDP)	22.4	23.8 ^a
<i>Other benchmark coefficients</i>		
Interest rate p.a. (in %)	5.0	–
Bequest (in % of GDP)	4.2	4.7-7.1 ^c
Human capital formed on-the-job (in %)		
- lower secondary education	22.8	–
- higher secondary education	12.7	–
- tertiary education	16.4	–
Educational participation (in %)		
- lower secondary education	60.3	65.7 ^b
- higher secondary education	26.8	20.3 ^b
- tertiary education	12.9	13.6 ^b
Wage premium on tertiary education (in %)	49.2	48.4 ^d

Source: ^aIdW (2009), ^bAB (2008), ^cBraun (2002),

^dStrauss and de La Maisonnette (2007).

macroeconomic situation in Germany. The interest rate of 5.0 percent per year is the same as the one we used in our estimation procedure. The amount of human capital produced via on-the-job training in the different educational classes is depicted as a fraction of initial human capital h_{j_s} .⁵ The educational participation rates are the number of people in different educational programs (according to the ISCED standard) as a fraction of the overall population that currently is in educational programs. The share of lower secondary education

⁵ A value of 1% consequently means that the agent increases his labor efficiency throughout the life-cycle by 1% of the initial human capital he has when entering the labor market.

participants is relatively low, compared to the German data, as we assume a dropout age of 15, whereas in reality there are also people dropping out at 16.

4 Simulation results

This section presents simulation results from our model. We thereby proceed in the following way. Starting from the long-run equilibrium described in Table 6, we implement some educational financing reform and compute the resulting new long-run equilibrium. In order to obtain comparability, we fix general government expenditure and government debt per capita and let the consumption tax rate balance the government's period-by-period budget.

4.1 Privatizing tertiary education

In Germany, at the moment, tertiary education is (nearly) completely publicly subsidised, i.e. government pays for all the direct costs of tertiary education.⁶ Coming from such a situation, we will first study the effects of a pure privatization of the tertiary education system. We therefore calculate the per student cost of education in our initial steady state and collect this amount as tuition fees from every student in every year of tertiary education. This seems to be an extremely radical reform of the education system, however, it allows us to quantify all the different effects that are at work in our model. In order to strengthen the necessity of endogenous schooling, general equilibrium price determination and endogenous initial distribution of agents across socio-economic background, in the left column of Table 7, we will start from a partial equilibrium model, where all these features are absent. With every new simulation, we then gradually move into the direction of the general equilibrium model described in Section 2.

Starting from a model with exogenous schooling, fixed prices and exogenous group densities,⁷ privatization of tertiary education has very little effects. Capital and therefore output rise slightly, as especially agents in the first periods of life, before going into tertiary education, save more in order to distribute the burdens from tuition over a broader period of their life. As prices are fixed, the interest rate stays at its initial value. With the expenditure on tertiary education now being financed directly by students, the consumption tax rate decreases by 1.8 percentage points, as the expenditure was 1.1 percent as a fraction of GDP

⁶ Obviously, government does not pay for students' overall cost of living

⁷ Schooling choice, prices and group densities are fixed at the initial equilibrium values reported in the previous section.

Table 7: Privatizing tertiary education

Simulation number	(1)			(2)			(3)			(4)			
Group densities				fixed		fixed					endogenous		endogenous
Prices				fixed		fixed					endogenous		endogenous
Schooling choice				fixed		endogenous					endogenous		endogenous
Capital ^a				0.7		-17.3		-2.4		-3.0			
Output ^a				0.6		-21.4		-2.9		-3.2			
Interest rate ^b				0.0		0.0		0.0		0.0			
Cons. tax ^b				-1.8		3.7		-0.8		-0.7			
Wage premium ^b				0.0		0.0		46.6		50.2			
Human capital index ^a				0.0		-11.3		-3.5		-3.6			
s =	1	2	3		1	2	3		1	2	3		
Labor ^a	1.0	1.7	-0.7		19.8	53.1	-73.3		15.2	16.8	-25.3		17.3 17.6 -26.9
Wages ^a	0.0	0.0	0.0		0.0	0.0	0.0		-11.2	-12.0	19.9		-12.4 -12.6 21.5
Fraction of ^b	0.0	0.0	0.0		4.7	23.7	-28.4		2.6	2.6	-8.2		2.8 5.6 -8.4
Schooling choice ^b													
- s _p = 1	0.0	0.0	0.0		0.9	10.2	-11.1		3.2	3.6	-6.9		2.0 4.6 -6.6
- s _p = 2	0.0	0.0	0.0		4.0	26.0	-30.1		3.7	9.3	-12.9		1.6 6.9 -8.5
- s _p = 3	0.0	0.0	0.0		7.5	28.2	-35.6		1.2	2.6	-3.8		-0.1 1.0 -0.9
s =	1	2	3		1	2	3		1	2	3		
Welfare change ^c	0.73	1.22	-4.90		-1.39	-1.03	-7.57		-3.95	-3.98	-2.83		-4.88 -4.67 -2.52
s _p =	1	2	3		1	2	3		1	2	3		
Welfare change ^c	-0.22	-1.72	-2.85		-1.13	-0.91	-6.24		-4.52	-4.54	-4.38		-5.06 -5.15 -3.50
Total welfare change ^c	-1.84					-3.02				-4.41			-5.01

Change in ^apercent over initial equilibrium, ^bpercentage points, ^cpercent of initial resources.

in the initial equilibrium and consumption is about 60 percent of GDP. The wage premium on tertiary education as well as the human capital index, which denotes per capita human capital of the working population, stay constant, as prices and schooling choice are fixed.

Labor supply especially increases for agents with lower education level. This is due to the fact that now students in the upper secondary education sector that might become college students afterwards and college students themselves, who provide labor of types $s = 1$ and $s = 2$, respectively, now work longer in order to compensate for the strongly binding liquidity constraints during their college years. This finding is in line with Garriga and Keightley (2007). For fully educated agents, we find a decrease in labor supply, as the price of consumption drops with the consumption tax rate and therefore leisure consumption increases. Wages and the fraction of people having completed different educational systems obviously can't change, because prices and schooling choice are fixed.

Finally, we report welfare changes for different groups. In the first line, we compute the average consumption equivalent variation of agents in different educational levels at the moment they can be distinguished, i.e. $j = 1$ for $s = 1$ and $j = 6$ for $s = 2$ and 3 .⁸ People enrolling in college obviously experience strong welfare losses, as they have to carry the direct costs from education themselves and their liquidity constraints now bite much stronger than in the initial equilibrium. With the consumption tax rate decreasing, lower educated households, on the other hand, gain from this reform. In the next line we decompose welfare change in the initial year $j = 1$ with respect to different socio-economic backgrounds. Now, we find welfare losses for all different types of agents due to the tremendous loss in student's welfare which can't be offset by welfare gains of other types. Welfare losses obviously have to increase with socio-economic background, as the ex-ante probability of becoming a student rises with parental education level s_p . Finally, aggregating over s_p , ex-ante welfare also has to decrease.

In the second column of Table 7, we relax the assumption of fixed schooling choice and let households decide endogenously about their schooling level. Capital and output now decrease tremendously due to the huge decline in the number of high skilled agents and therefore high income earners. In contrast to the previous simulation, the consumption tax rate has to increase in order to compensate for the shortfall in tax revenues caused by a decreasing income tax base. With the fraction of lower skilled agents in the population increasing, the human capital index decreases by 11.3 percent. Labor supply in the lower two educational classes has to rise, since the number of people choosing these education levels increases. The opposite obviously is the case for the third class. We find that the number of

⁸ Starting with $j = 6$ instead of $j = 11$ for the highest educational class, we cover the whole period of study with all the related burdens for those agents.

students decreases tremendously by about 28 percent, because the costs of tertiary education now have to be completely carried by students and liquidity constraints bite much stronger than before.

The matrix in the rows called "Schooling choice" shows the behavior of people with different socio-economic backgrounds, i.e. parents' educational levels s_p . We can read the columns as follows: due to the reform, the ex-ante probability of going to college for a child whose parents have low education decreases by 11.1 percentage points. Households enroll into college less often after the privatization of tertiary education, as they now have to carry the costs of education themselves and their liquidity constraints bite much stronger. In addition, we find that the probability of attending college is reduced much more for students with higher socio-economic backgrounds. However, we have to keep in mind, that those households already tended to go to college more often in the initial equilibrium. If one recalls that only 11.7 percent of agents with low skilled parents, i.e. $s_p = 1$, went to college before the reform, a reduction of 11.1 percentage points means a nearly 100 percent decline in the number of students for this class. For households with $s_p = 2$, the reduction consequently is around 90 percent, whereas for $s_p = 3$ agents, it only amounts to 61 percent.

As for the welfare of agents, we see that the welfare difference between agents of lower education and highest education level stays rather constant at about 6 percent of initial resources. However, aggregate welfare declines with the decrease in capital and the accompanying decrease in bequests.

In the next simulation, we assume prices to be determined endogenously. Complete privatization of tertiary education now comes with a long-run decline in assets of 2.4 percent, since the number of students and therefore the number of high earners still is reduced. This leads to a reduction in output of 2.9 percent. With overall labor supply being affected in the same direction, the interest rate stays constant. The consumption tax rate declines by about 0.8 percentage points due to the fallen need for educational spending. However, this move is rather modest, compared to simulation (1), as both the income and the consumption tax base are narrowed by the reform. The expected wage premium of tertiary education increases by 46.6 percentage points, which means it nearly doubles. This is due to the fact that wages of secondary and tertiary educated earners are spread. Finally, the human capital index decreases with the fallen number of students in the population.

As labor supply again is shifted towards lower schooling levels, wages react in the opposite way. Note that the spread in wages makes human capital a more risky investment, which in turn enforces the reduction in college graduates. The overall number of university graduates thereby declines by 8.2 percentage points, which means a reduction of over 20 percent of students.

We find that especially schooling choice of agents with poorer backgrounds is influenced by the reform, as they can't easily afford the tuition fees. The reduction in college participation rates is lower for class 1 than for class 2, because children from the lowest socio-economic background already didn't choose to go to college very often in the initial equilibrium. In addition, we see that the vast increase in returns for tertiary education due to the wage spread even for children with better educated parents does not provide enough incentive to go to college more often. This is due to the accompanying rise in tertiary education investment risk and the fact that students now have to pay for their costs of education themselves.

Interestingly, now the welfare of college students is higher than that of agents from lower educational classes, because of the decrease in wages for lower income earners and the tremendous rise in the college wage premium. In terms of welfare of agents with different socio-economic backgrounds, i.e. before the first schooling choice is made, we find a strong loss of 4.38 to 4.54 percent of initial resources. This is due to several reasons: the decline in tertiary education rates, harder binding liquidity constraints during the phase of tertiary education and the decline in assets which comes with decreasing bequests. With the huge drop in wages for lower educated households and the resulting rise in inequality, the overall welfare loss is higher than in Simulation (2), although bequests decline much less.

In the last simulation, in the righter column of Table 7, we now let the initial distribution of agents across different parental backgrounds be endogenous.⁹ As one can see, the macroeconomic effects are pretty much the same as in the exogenous group density case. However, the schooling choice matrix is heavily affected. This is due to the fact that the initial distribution of agents now changes in the long-run exactly in the way as the fraction of people in different educational classes (see line "Fraction of"). The dynamics of schooling choice is therefore as follows: resulting from the privatization reform, people of all classes choose to go to college less often. In the long-run, this leads to a reduction in college graduates and therefore a reduction in the number of people whose parents are rich. As the number of people with poorer socio-economic backgrounds, who do not go to college so often, increases, the number of college graduates decreases further. With the reaction in factor prices, the incentive for a single individual to go to college now again rises and, hence, the number of households joining the tertiary education sector tends to increase for each educational background. Neglecting the dampening effect via a change in initial distributions, a model of exogenous distribution consequently leads to an overestimation in schooling choice responses. It might even be that reactions change signs, as in the case of people with rich socio-economic background.

⁹ I.e. schooling choice affects the amount of people in different educational classes, which in turn determines the initial distribution of people across different parental backgrounds.

As the spread between college workers and those of other educational classes even increases and the expected tertiary education premium rises, high skilled agents are better off compared to the previous simulation. In addition, in terms of socio-economic backgrounds, those who tend to be lower educated ($s_p = 1, 2$) lose and people from richer socio-economic background gain. This leads to a reduction in ex-ante welfare, compared to the previous case, of 0.6 percent.

Summing up, we find that endogenous determination of prices and initial distribution of agents across socio-economic backgrounds has a major impact on the model results coming from privatization of tertiary education. Changes in wages for different types of labor widen the gap between lower and high skilled agents. As a consequence, students are better off compared to workers from other educational classes, since the falling consumption tax rate can't offset the decrease in income. In addition, endogenous determination of initial distribution across parental education levels s_p alters the schooling choice reaction of agents and widens the gap between higher and lower skilled agents. As a consequence, aggregate welfare decreases.

4.2 The design of governmental student loans

A larger part of the welfare losses and the declining number of students, resulting from privatization of tertiary education, are due to stronger binding liquidity constraints. In order to relax this effect, we now simulate a reform proposed by García-Peñalosa and Wälde (2000). Together with the privatization of tertiary education, we introduce an income contingent student loan system. In this system, students receive exactly the amount of tuition fees during their period of study from the government. Having graduated, there are 5 repayment-free years after which the loan has to be paid back over a time-span of 10 years. However, the loan is income contingent, i.e. only students who pass the final exam and do not drop back to the higher-secondary educational class have to pay it back. The remaining burden coming from high-school drop-outs will be financed by consumption taxes. Hence, in addition to loosening liquidity constraints early in life, this type of loan provides partial insurance against the risk of college failure.

The results from such a reform can be seen from the left part of Table 8. Capital decreases even further, compared to Simulation (4) in Table 7, although the number of students is not reduced that much. This is a natural reaction from people being allowed to run into debt in the first periods of life. Aggregate labor supply is hardly affected. Therefore, output decreases only by 1.3 percent and the interest rate rises slightly. As the income tax base is not narrowed, the consumption tax rate can decrease much more compared to the previous

Table 8: Student loans

<i>Simulation number</i>	<i>(5)</i>			<i>(6)</i>			<i>(7)</i>			
<i>Privatization</i>	<i>yes</i>			<i>no</i>			<i>no</i>			
<i>Interest</i>	<i>with</i>			<i>with</i>			<i>without</i>			
Capital ^a	-3.1			-0.8			0.0			
Output ^a	-1.3			0.2			0.5			
Interest rate ^b	0.2			0.1			0.1			
Cons. tax ^b	-2.3			-0.7			0.1			
Wage premium ^b	9.9			-7.9			-10.5			
Human capital index ^a	-1.7			0.6			1.2			
	<i>s =</i>	<i>1</i>	<i>2</i>	<i>3</i>	<i>1</i>	<i>2</i>	<i>3</i>	<i>1</i>	<i>2</i>	<i>3</i>
Labor ^a		4.5	4.4	-6.2	-3.0	-3.2	6.1	-4.4	-4.5	7.8
Wages ^a		-4.2	-4.1	3.3	2.1	2.2	-4.1	3.4	3.5	-4.9
Fraction of ^b		1.2	2.2	-3.5	-0.4	-0.3	0.7	-0.8	-1.0	1.8
Schooling choice ^b										
- <i>s_p</i> = 1		0.5	0.9	-1.4	-0.9	-0.3	1.2	-1.1	-0.6	1.7
- <i>s_p</i> = 2		0.5	2.3	-2.8	-0.3	-0.8	1.1	-0.5	-1.5	1.9
- <i>s_p</i> = 3		0.5	1.9	-2.4	0.2	0.3	-0.5	0.1	-0.2	0.2
	<i>s =</i>	<i>1</i>	<i>2</i>	<i>3</i>	<i>1</i>	<i>2</i>	<i>3</i>	<i>1</i>	<i>2</i>	<i>3</i>
Welfare change ^c		-0.51	-0.44	-0.96	1.21	1.19	0.91	1.33	1.28	1.16
	<i>s_p</i> =	<i>1</i>	<i>2</i>	<i>3</i>	<i>1</i>	<i>2</i>	<i>3</i>	<i>1</i>	<i>2</i>	<i>3</i>
Welfare change ^c		-0.51	-0.59	-0.79	1.32	1.31	0.73	1.44	1.46	0.94
Total welfare change ^c		-0.80			1.13			1.34		

Change in ^apercent over initial equilibrium, ^bpercentage points, ^cpercent of initial resources.

cases. The wage premium increases by 9.9 percentage points and the human capital index decreases by 1.7 percent, since the fraction of students is reduced less than before.

The reactions of labor supply, wages and fraction of students are much less intense, as students now can easily afford tuition fees during their time of study. Due to the differences between people with different educational backgrounds being much smaller after graduation than before (all of them are high-wage earners then), the reform affects households with different educational backgrounds nearly in the same way, i.e. it seems to be socially more acceptable. The effect is slightly higher for people with richer socio-economic backgrounds as they tended to go to university in the initial equilibrium more often. A remarkable point is that, even though income contingent loans do provide insurance against tertiary education risk, people enroll in college less often than under the public education scheme. This is

due to the fact that people still have to pay for their tertiary education on their own, which derogates the rental rate on tertiary education.

In opposite to the previous simulation, in terms of welfare we now find that college students are worse off than households in other educational classes, as the reaction of marginal products of labor is much smaller than before and the consumption tax rate decreases further. In addition, agents with richer parents are hurt more by the reform. This is because those households study with the highest probability and, therefore, publicly financed higher education distributed towards those agents in the initial equilibrium. As this redistribution mechanism is absent after the reform, they lose most. Note, first, that it is not clear to which extend welfare losses in the long-run are due to intertemporal redistribution. With the decline in assets, bequests decrease nearly in the same manner and therefore long-run welfare decreases. Second, ex-ante aggregate welfare loss is higher than any educational class specific welfare loss. This comes from the initial distribution of agents with different socio-economic backgrounds changing. With the declining number of students, the ex-ante probability of having rich parents decreases. As people with lower socio-economic background do enroll into college less often, people tend to be lower educated and therefore earn less income. This second effect is only incorporated in the ex-ante aggregate welfare, not in the welfare of people with different educational background, i.e. after their socio-economic status is revealed.

In the previous section we found that privatization of tertiary education comes with a vast reduction in the number of students. However, income contingent loans work against this problem. Hence, we now want to quantify the effects of a governmental loan system that is introduced on top of the German publicly financed tertiary education system in order to finance student's cost of living and further relax borrowing constraints. We hereby want to focus on the schooling choice of households with different parental backgrounds and the influence on the number of students in the economy. Therefore, we introduce in Simulation (6) an income contingent loan of 6000€, which amounts to the standard rate of the German BAföG, a student assistance system, see Statistisches Bundesamt (2005). The results from such a reform can be seen from the middle column of Table 8.

Capital decreases with liquidity constraints being loosened. With a slight increase in labor supply due to a higher fraction of students, output as well as the interest rate decline slightly. A student loan system in which students have to pay back loans plus interest runs some governmental surplus, as the natural interest rate in our model equals the population growth rate $n = 0$. Together with the increase in income tax revenues, this over-compensates the burden from income contingency and, consequently, consumption taxes fall. Finally, as the number of students as well as labor supply in the highest educational class increase, wages react in the opposite way and the wage premium decreases. The human capital index obvi-

ously has to rise.

We can see that the number of students increases by 0.7 percentage points. In addition, the schooling choice of people with different educational backgrounds is affected. Whereas the number of students increases by around 1 percentage points in the two lower socio-economic classes, agents with rich parents reduce their college enrolment by 0.5 percentage points. The decrease in college enrolment for the latter is a consequence of the decline in college graduate wages of around 4 percent.

Welfare effects are now positive for all three types of agents. This is mainly due to inter-generational redistribution. As the consumption tax decreases, long-run generations gain from the reform. Surprisingly, college students, who should be the main beneficiaries from additional student loans, gain less than households from lower schooling levels. This is mainly due to the reduction in wages. As a consequence, agents with richer socio-economic backgrounds gain less than the poorer, because they go to university more often.

In the last column of Table 8, we implement an income contingent loans system, where loans have to be paid back without interest. This is close to the practice of the BAföG in Germany and acts like an additional subsidy to higher education. Here, obviously, the system does not run a surplus anymore and the consumption tax has to rise slightly. Due to a larger fraction of the population now being highly educated and the progressive tax schedule, labor income tax revenues rise significantly. Hence, most of the burden arising from income contingency is carried by college graduates, which is why the rise in consumption tax rates is pretty small. The common argument that mainly people with lower education carry the burden of subsidies to higher education therefore does not hold in our model.

With the number of students increasing significantly by 1.8 percentage points, the wage and therefore the wage premium for tertiary education decrease further compared to the previous simulations. Note that in this simulation college enrolment rates increase for all three different types of socio-economic backgrounds. However, due to stronger binding liquidity constraints, the effect is larger for agents with poorer parents. Finally, with tertiary education being subsidised, welfare for all three types of households as well as aggregate welfare slightly increase. However, we still find that college students gain less than households from lower education classes, as the college wage premium is reduced significantly.

4.3 Sensitivity analysis

In order to check for the robustness of our results, we perform a sensitivity analysis. The first row in Table 9 repeats the results from the last reform in Table 8. We first study the same reform under the assumption of a small open economy with an interest rate equal

to the one in our initial equilibrium. As we see nearly no change in capital and interest rate in the previous simulations, the results obviously do not change very much. Next, we keep the assumption of a small open economy in order to hold the capital output ratio constant and obtain comparability. We then change some of the central parameters of the model. Note that, in the column "Incr. in students" we show the percentage change in the number of students, as, due to parameter changes, the amount of college students in the initial equilibrium might change.

Table 9: Sensitivity analysis

<i>Open economy</i>	ϕ	γ	ρ	χ	p^f	ξ	<i>Assets</i>	<i>Cons. tax rate</i>	<i>Wage premium</i>	<i>Incr. in students^a</i>	<i>Welfare</i>
no	2.00	0.50	0.60	1.41	0.20	0.16	-0.1	0.1	-10.5	4.6	1.34
yes							-1.0	0.1	-10.5	4.6	1.35
yes	0.00						-1.2	0.1	-10.0	4.1	1.32
yes		0.70					-0.2	0.0	-2.7	0.0	0.20
yes			0.30				0.1	0.0	-12.6	7.4	-0.01
yes				0.50			-1.9	0.3	-11.4	0.0	1.18
yes					0.00		-2.6	-0.2	-10.9	0.7	1.69
yes						0.00	0.4	-0.1	-15.2	12.6	0.49

^ain percent of number in initial equilibrium.

In order to isolate risk aversion from intertemporal substitution, we follow Epstein and Zin (1991) and rewrite the preference structure of the representative consumer by

$$V(z_j) = \max_{c_j, \ell_j, e_j} \left\{ u(c_j, \ell_j) + \delta \psi_{j+1} E \left[V(z_{j+1})^{1-\phi} \right]^{\frac{1-\frac{1}{\gamma}}{1-\phi}} \right\}^{\frac{1}{1-\frac{1}{\gamma}}},$$

The parameter ϕ defines the degree of (relative) risk aversion. For the special case $\phi = \frac{1}{\gamma}$ we are back at the traditional expected utility specification discussed above, see Epstein and Zin (1991, 266). Consequently, setting relative risk aversion at $\phi = 2.0$ yields the benchmark equilibrium reported in Table 6.

If we now set the relative risk aversion at $\phi = 0$, we only find slight changes of the results. This suggests that the insurance provision against tertiary education risk only plays a minor role in our simulations. The increased number of students is therefore mostly due to subsidies and loosened liquidity constraints. We now set back relative risk aversion at a value of 2.0 and change the intertemporal rate of substitution to 0.7. The consumption profile therefore becomes steeper over the life-cycle and liquidity constraints tend to bind much less. Hence, a policy that tries to loosen liquidity effects has nearly no influence on college

enrollment and the macroeconomy. The remaining welfare gains are due to the insurance provision arising from income contingency. Changing the intratemporal rate of substitution to 0.3 decreases the elasticity of labor supply. This makes households less sensitive to the development of marginal products. Hence, the decline in wages for college workers has a minor effect and the fraction of college students increases compared to the previous simulations. However, we find no welfare gain anymore, since wages for college workers now decrease more than 9 percent and those of lower educated do not rise. Next we set the elasticity of substitution between different types of labor from 1.41 to 0.5. Consequently, marginal products will react much stronger in order to insure that the composition of labor does not change so much. As a result the number of students does not increase and welfare gains are lower compared to the benchmark. However, the macroeconomic and welfare effects are pretty much the same. Setting the college failure rate at 0, in the initial equilibrium there is already a huge number of students. Consequently, a reform to improve the number of students has smaller effects on the college participation rates than in the previous reforms. Finally, eliminating intergenerational transfers, i.e. $\tilde{\zeta} = 0$, liquidity constraints obviously bind much stronger and the number of students increases significantly with the reform. However, aggregate welfare declines with a stronger decrease in the college wage premium.

5 Discussion

In this paper, we study the long-run effects of educational finance policies and student loan systems. We therefore construct a model in the tradition of Heckman et al. (1998) and Galipoli et al. (2008). Our model features two schooling choices and therefore three schooling classes, lower secondary, higher secondary and tertiary education. As students might fail in college, tertiary education is a risky investment. In addition to choosing their optimal level of education, workers can build human capital on the job, where labor income underlies a stochastic process. A detailed modeling of the German government sector complements our analysis.

We find in this model, which is carefully calibrated to the German economy in 2007, that privatization of tertiary education comes with a vast reduction in the number of students, an increase in the college wage premium and long-run welfare losses of around 5 percent of initial resources. Our model accounts for the fact that schooling choice of agents affects the initial distribution of households over different socio-economic backgrounds in the long-run. Put simply, if less people decide to enroll at college, there will be less children whose parents are college graduates. A major point of the paper is that, if one takes this effect

into account, the schooling choice behavior of agents with different backgrounds is significantly affected. Surprisingly, we find that from privatization of tertiary education, students are better off compared to workers from other educational classes, since the college wage premium nearly doubles. The decline in consumption tax rates can't offset the decrease in labor income for lower educated households. This result is in contrast to common theoretical models of schooling, where wages usually are fixed, see e.g. García-Peñalosa and Wälde (2000).

In addition, our model predicts that the declining college enrolment rates and welfare losses for tertiary education privatization can't be offset by an income contingent student loan system, which shifts the burden of tuition to later periods in life, hence, relaxes borrowing constraints, and provides insurance against college failure. However, due to the dampened reactions in the number of students causing only a slight increase in the college wage premium as well as a stronger decline in consumption tax rates, college workers are now worse off compared to lower skilled workers.

We also quantify the effects of student loan schemes that are implemented on top of the current publicly financed tertiary education system in Germany. Two major points arise from our analysis. First, income contingent loans might reduce enrolment rates for people with richer socio-economic backgrounds due to the reduction in the college wage premium. Second, loans on which students don't have to pay interest, i.e. loans that act like a tertiary education subsidy, improve the college enrolment situation for agents from all kinds of socio-economic backgrounds. With income revenues increasing with this reforms, the burdens arising from income contingency are carried to a large part by successful college graduates and, hence, the consumption tax rate increases only slightly. Consequently, the common argument that mainly people with lower education carry the burden of subsidies to higher education does not hold in our model.

In the future, we plan to extend the model by a transition path and a Lump-sum Redistribution Authority (LSRA) in the spirit of Auerbach and Kotlikoff (1987). It is not clear to which extend our welfare results depend on intergenerational redistribution. Consequently, a LSRA compensation could quantify the pure efficiency effects of educational finance reforms. In addition, with such a rich model of schooling choice and human capital formation, one could study the design of a optimal tax system. Optimal taxation has been studied in theoretical models, like e.g. in Jacobs and Bovenberg (2009) or Anderberg and Andersson (2003). Heckman et al. (1999) or Erosa and Koreshkova (2007), on the other hand, examine the effect of replacing a progressive tax system by a linear one in a numerical model of human capital formation. Most of these studies, however, either neglect the effects of riskiness in human capital or ignore the transition to a new long-run equilibrium resulting from a change in the tax structure. Another application of our model would be to study the opti-

mal design and progressivity of a pension system. As a pay-as-you-go pension prolongs the time of yield of human capital investment, it is not clear to which extend the often postulated privatization of social security delivers efficiency gains. On the other hand, the optimal progressivity of a pension system is to be studied between the conflicting priorities of risk insurance and encouraging people to build human capital.

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