Human Capital, Retirement and Pension Saving

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1 Introduction

Understanding the lifecycle interactions between investments in human capital, retirement choices and pension savings is highly policy relevant. Most Western governments will be confronted with the consequences of demographic ageing in the upcoming decennia. Tax bases will shrink due to the retirement of older generations of workers and outlays on state pensions and health care will rise substantially. If the number of pensioners rises substantially relative to the number of workers pension systems with strong intergenerational risk-sharing face difficulties as well, since it will become more difficult and costly to smooth pension risks over different generations by means of contribution adjustments. At the same time, individuals do not invest in skills, because they expect to retire early. And, individuals retire early because they have not invested in skills. As a result, many European countries are confronted with a vicious circle of low investments in training on-the-job of older workers and strong incentives to retire early.

Given these developments, policy makers are considering many policies to increase investment in skills, promote later retirement and pension savings. For example, all European countries have subscribed to the Lisbon agenda. One of its main targets is that the European Union average level of participation in Lifelong Learning should be at least 12.5% of the adult working age population (25-64 age group) by 2010. Most countries have started to implement 'life-long learning' policies to promote investments in OJT so as to raise labor productivity and to improve employability of especially older workers. In addition, governments aim to promote labor market participation of older workers and to improve their employability so as to broaden tax and premium bases. In particular, (early) retirement schemes and labor markets are reformed

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in order to stimulate later retirement. In the past, implicit taxes on continued work have often been so high that individuals were 'stealing their own wallet' if they did not retire early. Furthermore, many governments stimulate private pension saving, for example through tax-favored saving schemes, so as to reduce the dependency of pensioners on state pensions and collective occupational pension-schemes.

Unfortunately, too little is known about lifecycle interactions between learning, retirement and saving, both theoretically and empirically. Generally, training, (pension) saving and wage determination are separately analyzed, and no generally accepted theories are available to simultaneously address these issues. The consequence is that human capital policies are considered in isolation from retirement and pension policies. This paper demonstrates that ignoring important lifecycle interactions can be potentially very misleading and could well produce ill-founded policy conclusions.

The paper starts by making a first attempt to *systematically* analyze the interactions between human capital investments in OJT, retirement choices and pension saving. To that end, we develop a Ben-Porath (1967) human capital model of OJT which is firmly grounded in neoclassical human capital theory (see for example Mincer, 1958, 1962, 1974; Schultz, 1963; and Becker, 1964). The model is extended with a discrete, endogenous retirement decision as in Jacobs (2009). We show that retirement and pension saving affect the incentives to invest in human capital over the lifecycle. By extending the time-horizon over which investments in skills materialize, a higher retirement age promotes investments in on-the-job training (OJT). Later retirement and OJT-investment are therefore complementary. Generous support for early retirement therefore indirectly discourages investment in OJT.

Individuals also make a lifecycle portfolio choice by investing in both financial and in human capital. Stimulating retirement savings implies that savings in human form are discouraged. The intuition is that the opportunity return at which future labor earnings are discounted increases. Equivalently, arbitrage between financial and human investments ensures that both assets must earn equal returns. Hence, human and financial capital are substitutes over the lifecycle. Simulations of the model with various tax and retirement policies provide important insights into the main mechanisms that are at work. Although this is of separate scientific interest, it is only done to provide a parsimonious framework that allows us to consistently organize our thoughts.

Moreover, labor market institutions and welfare state arrangements appear to be crucial to understand economic incentives for OJT investments. Labor markets institutions, such as employment protection, wage setting of unions, efficiency wages, deferred payment-schemes, and minimum wages, could rotate the wage profile over the lifecycle and may result in wage compression. This may be the consequence of various welfare state arrangements that affect wage-setting, such as benefits for sickness, disability, and unemployment, pensions, early retirement schemes. In addition, the value of outside options for workers typically increases as they become older. Both wage compression and rotation of wage profiles can harm the incentives to invest in skills. In particular, by reducing the wage differences between skilled and unskilled workers, the incentives to become skilled diminish. Further, by rotating the wage-profile over the lifecycle, younger workers will invest too much and older workers too little in human capital.

The following highly relevant policy-relevant implications finally appear from this analysis:

- Promoting life-long learning or later retirement will not be effective if strong disincentives caused by labor market institutions, early retirement schemes and incentives for pension savings remain in place.

- Promoting private savings for old-age may inadvertently create implicit taxes on skill formation and indirectly stimulate early retirement, thereby worsening the ageing problems.

The main message of this paper is that any policy reform should therefore take into account the dynamic interactions of OJT-investment, retirement and pension saving.

After having developed the theoretical structure, we will discuss in more detail i) its underlying assumptions, ii) its empirical content, and iii) various competing theories. In particular, we will pay attention to the assumptions we made on the functioning of labor and financial markets. Labor market distortions due to, for example, unions or minimum wages are expected to affect the incentives for OJT-training. Similarly, borrowing constraints or non-insurable risks affect the incentives to invest in human capital.

Furthermore, we aim to shed light on the empirical relevance of the theory. We argue that the empirical evidence is very much in line with the theoretical predictions of the model. However, due to important data limitations we cannot directly prove empirically that our standard human capital model causally explains lifecycle earnings. The most pressing problem is that investments in human capital are hard to measure by the analyst and most proxies used in empirical analyses have large shortcomings. We will elaborate on various theoretical, empirical and methodological issues when bringing the main theory developed in this paper to the data.

Other, competing theories of lifecycle earnings determination and investments in human capital could explain salient features of the data as well. We will therefore discuss theories of specific investments in human capital (Becker, 1964), and general training in distorted labor markets (Acemoglu and Pischke, 1998, 1999), incentive theories and deferred payment schemes (Lazear, 1976, 1979, 1981), learning-by-doing theories (Killingsworth, 1982; Heckman et al. 2002). We will argue that theories of specific investments and training in non-competitive labor markets have some empirical implications that are counter-factual. Moreover, learning-by-doing and on-the-job training models are hard to distinguish from each other once general equilibrium feedbacks have been taken into account. Theories on deferred payments are not concerned with human capital investments, but do probably explain part of the patterns found in earnings over the lifecycle.

We will argue that the remaining gaps in knowledge are large. In order to close the gaps, future research should be directed towards using structural models that aim to identify non-observable human capital investments by imposing theoretical structure on the data. However, the identification of these non-observables is as good as the theoretical structure used. Hence, better theories are needed to understand investments in human capital, retirement and pension choices over the lifecycle. In particular, developing models with labor market distortions appears to be key in understanding lifecycle choices in European-style labor markets. As regards the data, micro-panel data are needed to properly estimate lifecycle models. We do not expect to learn much from cross-country panel studies, since the time-series variation is often too limited

and identification of effects on the cross-sectional dimension of the data is often very problematic from an econometric point of view. Researchers from multiple sub-disciplines should join forces to obtain scientific progress. In particular, structural microeconometricians and micro-, macro-, and labor theorists should cooperate.

2 A stylized model of training, retirement and saving

We follow Heckman and Jacobs (2006) and Jacobs (2009) by adding an endogenous retirement decision to the otherwise standard Ben-Porath (1967) model of OJT-investments, see also Heckman (1976) and Weiss (1986). This is the canonical model to think about OJT. Although savings are made to ensure consumption smoothing over the lifecycle, most savings will be made for the retirement period in which individuals have no labor earnings. We abstract here from endogenous (initial) education and labor supply decisions on the intensive margin, i.e. hours of work. A partial equilibrium setup is chosen in which the paths of the rental rates for human capital and the interest rate are exogenously given. This would be the case in small, open economies with perfect capital mobility and perfect substitution between labor types in labor demand. Capital and labor markets are perfectly competitive and frictionless. The latter assumptions are not innocent and we will return to them in detail later.

We assume that a representative individual is born at time $t = 0$ and has a life-span T which is exogenously given. At $t = 0$ the individual enters the labor market. The individual retires at date $R < T$. The time constraint states that total time in the labor market R and in retirement $T - R$ should equal the life-span T of the individual: $T = R + (T - R)$.

At each date, the individual derive instantaneous utility $U(C(t))$ from consumption $C(t)$. Individuals derive utility $X(T - R)$ from the years they are retired $T - R$. Retirement is a discrete decision to exit the labor market completely. We therefore assume that the retirement decision is not a zero hours worked 'corner-solution' (for more discussion, see Jacobs, 2009).

Life-time utility of the individual is a time-separable function of instantaneous consumption felicities and retirement utility

$$\int_0^T U(C(t)) \exp(-\rho t) dt + X(T - R), \tag{1}$$

with $U'(C(t)) > 0$, $U''(C(t)) < 0$, $X'(T - R) > 0$ and $X''(T - R) < 0$. ρ is the subjective rate of time preference.

The individual starts his life with $A(0) \equiv A_0 \equiv 0$ in financial assets, which are normalized to zero for convenience. Borrowing and lending on a perfect capital market is possible at constant real interest rate r. Upon entering the labor market, the individual may devote part of his time to training on-the-job. The time constraint during the working life implies that the fraction of time working $1 - I(t)$, plus the fraction of time invested in training $I(t)$ should be equal to the total time endowment, which is normalized to one. The individual earns gross labor income $W(1 - I(t))H(t)$. W is the rental rate of human capital, which is time-invariant. $H(t)$ is the stock of human capital which is gathered through training on-the-job in a manner that will be made precise below.

The flow budget constraints until retirement ($0 < t \leq R$) state that the increase in financial assets should equal total interest income, net labor income minus consumption expenditures

$$\dot{A}(t) = (1-\tau_A)rA(t) + (1-\tau_L)W(1-I(t))H(t) - C(t), \quad 0 < t \leq R. \tag{2}$$

A dot denotes a time derivative (i.e., $\dot{A}(t) = dA(t)/dt$), τ_L is the labor income tax rate, and τ_A is the interest tax (or subsidy when negative).

During retirement ($R < t \leq T$) the individual runs down his accumulated assets for consumption purposes:

$$\dot{A}(t) = (1-\tau_A)rA(t) + (1-\tau_P)P - C(t), \quad R < t \leq T, \tag{3}$$

where P is the time-invariant retirement benefit, and τ_P denotes the rate at which retirement benefits are taxed. One should interpret the pension benefit P as that part of pension benefits that is actuarially completely non-neutral, since individuals only receive retirement benefits conditional upon full retirement. Any actuarially fair pension savings are covered by the voluntary saving decision.[1] The individual has no bequest motive and ends his life with zero wealth: $A(T) \equiv 0$.

The individual can increase his human capital by allocating time $I(t)$ to learning activities, while foregoing labor earnings. Without loss of generality, it's assumed that on-the-job training does not require direct costs (for that case, see Ben-Porath, 1967; Heckman, 1976).[2] The individual starts out with $H(0) \equiv H_0 > 0$ units of on-the-job human capital when he enters the labor market. On-the-job human capital accumulates according to a Ben-Porath (1967)-type production function

$$\dot{H}(t) = BF(I(t)H(t)) - \delta H(t), \quad 0 < t \leq R, \tag{4}$$

where $B > 0$, $F'(I(t)H(t)) > 0$, $F''(I(t)H(t)) < 0$. B is a general productivity parameter. There is dynamic complementarity in human capital formation on-the-job because the marginal product of training investments increases with the level of human capital $H(t)$. Hence, large (small) early investments in human capital make later investments in human capital more (less) productive. δ denotes the rate of depreciation of human capital.

Integration of the asset accumulation constraints and imposing the initial and terminal conditions on financial wealth ($A(0) = A(T) = 0$) gives the life-time budget constraint of the individual

$$\int_0^T C(t)\exp(-r^*t)dt = \int_0^R W^*(1-I(t))H(t)\exp(-r^*t)dt + \int_R^T P^*\exp(-r^*t)dt, \tag{5}$$

where $r^* \equiv (1-\tau_A)r$, $W^* \equiv (1-\tau_L)W$, and $P^* \equiv (1-\tau_P)P$ denote the after-tax values of the interest rate, rental rates, and pensions.

[1] Note that in many countries tax systems feature tax-deductibility of pension contributions, taxed pension benefits, and no taxation of pension returns. This is equivalent to setting the tax on (pension) saving to zero ($\tau_A = 0$).

[2] Empirically, forgone earnings are the major cost of investment in human capital. In addition, firms and workers can always make the costs of training effectively deductible by letting the firm pay the direct costs in exchange for lower wages.

The individual maximizes life-time utility by choosing consumption (saving), on-the-job training, and retirement subject to the household budget constraint, the time constraints, and the accumulation equation for on-the-job human capital. The Hamiltonian for this optimal control problem can be written as follows

$$\max_{\{C(t),R,I(t),H(t)\}} \mathcal{H} \equiv \int_0^T U(C(t))\exp(-\rho t)dt + X(T-R) + \mu(t)\left[BF(I(t),H(t)) - \delta H(t)\right] \quad (6)$$
$$+\lambda_0\left[\int_0^R W^*(1-I(t))H(t)\exp(-r^*t)dt + \int_R^T P^*\exp(-r^*t)dt - \int_0^T C(t)\exp(-r^*t)dt\right],$$

where λ_0 is the marginal utility of life-time income, $\mu(t)$ is the co-state variable at time t associated with the on-the-job human capital accumulation equation, and H_0 is given. In the remainder we assume that all solutions to the maximization problem are interior. Therefore, we ignore the non-negativity constraints on all decision variables. Most of these constraints are trivial, except for one: the non-negativity constraint on working time ($I(t) \leq 1$). This implies that individuals always work some positive amount of time (if not retired) and are never choosing a corner where they invest full-time in OJT.[3]

We assume that the first-order conditions for a maximum are necessary and sufficient[4]

$$\frac{\partial \mathcal{H}}{\partial C(t)} = U'(C(t))\exp(-\rho t) - \lambda(t) = 0, \quad 0 < t \leq T, \quad (7)$$

$$\frac{\partial \mathcal{H}}{\partial R} = -X'(X-R) + \lambda_R\left((1-\tau_L)W(1-I_R)H_R - (1-\tau_P)P\right) = 0, \quad (8)$$

$$\frac{\partial \mathcal{H}}{\partial I(t)} = \mu(t)BF'(I(t)H(t))H(t) - \lambda(t)(1-\tau_L)WH(t) = 0, \quad 0 < t \leq R, \quad (9)$$

$$\frac{\partial \mathcal{H}}{\partial H(t)} = \mu(t)\left[BF'(I(t)H(t))I(t) - \delta\right] + \lambda(t)(1-\tau_L)W(1-I(t)) = -\dot{\mu}(t), \quad 0 < t \leq R, \quad (10)$$

where $\lambda(t) \equiv \lambda_0\exp(-r^*t)$ denotes marginal utility of income at date t. In addition we have to impose a transversality condition on the co-state variable stating that the marginal value of human capital is zero at the date of retirement

$$\mu_R H_R \exp(-(1-\tau_A)rR) = 0. \quad (11)$$

Using standard routines we obtain the Euler equation for consumption

$$\frac{\dot{C}(t)}{C(t)} = \theta(t)\left((1-\tau_A)r - \rho\right), \quad 0 \leq t \leq T, \quad (12)$$

where $\theta(t) \equiv \left(-\frac{U''(C(t))C(t)}{U'(C(t))}\right)^{-1}$ is the intertemporal elasticity of substitution in consumption. If the rate of time preference is lower than the real after-tax return on financial saving, consump-

[3]Like Heckman (1976) we think that the analysis of 'corners', as pursued for example in Ben-Porath (1967) and Weiss (1986), distracts from the main mechanisms at work. In particular, an initial phase during the lifecycle with mainly training can be seen as a phase with low labor earnings, not necesarily a phase with zero earnings.

[4]Sufficiency is not automatically guaranteed due to the feedback between retirement and human capital accumulation. Only sufficiently strong decreasing returns in human capital formation and sufficiently concave retirement sub-utility ensure an interior solution. We assume that these conditions are met.

tion features an upward sloping profile over the lifecycle. A larger intertemporal elasticity of substitution results in a stronger upward sloping consumption profile and a stronger sensitivity of saving with respect to net after-tax returns.

Optimal retirement is given by (note that $I_R = 0$ at the end of the working life, see below)

$$\frac{X'(T-R)}{\lambda_R} = (1-\tau_R)\,(1-\tau_L)WH_R. \tag{13}$$

$\tau_R \equiv \frac{(1-\tau_P)P}{(1-\tau_L)WH_R}$ denotes the net replacement rate of net retirement income in terms of net final earnings. τ_R is the implicit tax rate on continued work due to non-actuarially fair pension benefits. The marginal willingness to pay for an additional year in retirement should be equal to the marginal costs of an extra year in retirement. The marginal benefit is the marginal rate of substitution between retirement utility and consumption at the date of retirement. The marginal costs are given by the value of the net forgone labor earnings in the last year on the labor market. Note that the implicit tax on retirement τ_R is added to the explicit labor tax τ_L on retirement. Both give stronger incentives to retire earlier. However, the direct tax is often overlooked in retirement studies, which focus mainly on the implicit tax. λ_R captures wealth effects in the retirement decision. Richer individuals have a lower marginal utility of income and retire earlier – ceteris paribus. Note that a higher tax on (pension) saving τ_A gives stronger incentives to retire later, since the effective discount rate at which retirement utility is discounted increases, since $\lambda_R = \lambda_0 \exp(-(1-\tau_A)rR)$. A lower interest rate thus effectively 'enlarges' the time-horizon over which decisions are made, since the future is less heavily discounted. The individual has stronger incentives to retire later if he has more human capital H_R, since this raises forgone labor earnings while being retired. Thus, better-skilled workers retire later when the income effect of higher skills are outweighed by the substitution effects of higher skills – ceteris paribus. Similarly, if individuals do not train and end their career with low levels of human capital, the incentive to retire will be stronger since the opportunity costs of doing so diminish.

Investment in on-the-job training is governed by

$$(1-\tau_L)W = m(t)BF'(I(t)H(t)), \quad m(t) \equiv \mu(t)/\lambda(t), \quad 0 \le t \le R. \tag{14}$$

This equation states that the marginal costs of an hour devoted to on-the-job human capital investment ($(1-\tau_L)W$) should be equal to the discounted value of the marginal benefits in terms of higher future wages $m(t)BF'(I(t)H(t))$. $m(t)$ discounts the stream of future wage increases $F'(I(t)H(t))$ back to time t. $m(t)$ is therefore the marginal value of one unit of human capital at time t. Investment in on-the-job human capital increases if the marginal value of one unit of human capital is large (high $m(t)$) and if the opportunity costs, in terms of forgone labor earnings, are low (low $(1-\tau_L)W$). Moreover, investments in human capital tend to increase if the individual has a larger stock of human capital (large $H(t)$). This is due to the dynamic complementarity of investments in human capital. Finally, investment in OJT increases if the individual has a higher exogenous productivity of learning B. B captures, for example, the level of initial education before entering the labor market. Thus, better educated individuals would invest more in OJT during the lifecycle.

From the first-order condition for $H(t)$ we find a first-order differential equation for the marginal value of a unit of human capital.

$$\dot{m}(t) - ((1-\tau_A)r + \delta)m(t) = -(1-\tau_L)W, \quad 0 \leq t \leq R. \tag{15}$$

This equation can be solved analytically (after using the transversality condition $m_R = 0$):

$$m(t) = \frac{(1-\tau_L)W}{((1-\tau_A)r+\delta)} \left(1 - \exp[((1-\tau_A)r+\delta)\,(t-R)]\right), \quad 0 < t \leq R. \tag{16}$$

The marginal value of a unit of human capital at time t is increasing with the effective net wage rate at date t, $(1-\tau_L)W$, decreasing with the depreciation adjusted real interest rate $((1-\tau_A)r+\delta)$, and decreasing with the remaining time-span over which the returns in human capital are harvested, i.e. a smaller $[1 - \exp[((1-\tau_A)r+\delta)\,(t-R)]]$. Note that the last term is an annuity term capturing the finite time-horizon of the investment in human capital. A higher interest rate (or depreciation rate) effectively shortens the time-horizon of individuals. The marginal value of human capital $m(t)$ is independent from initial wealth, due to the assumption of perfect capital markets. Hence, individuals with differing wealth endowments would make identical human capital investments (ceteris paribus).

The marginal value of human capital declines continuously over the lifecycle:

$$\dot{m}(t) = -(1-\tau_L)W \exp[((1-\tau_A)r+\delta)\,(t-R)] < 0, \quad 0 < t \leq R. \tag{17}$$

The reason is that the time-horizon over which the returns to the investments can be reaped diminishes as individuals age. Hence, investment in human capital $I(t)Ht)$ falls continuously over time, until it becomes zero at the date of retirement $t = R$. Intuitively, at the date of retirement investments have no value, since the returns on OJT are zero if individuals do not work anymore.

Substitution of $m(t)$ into the first-order condition for $I(t)$ in equation (14) gives an arbitrage condition saying that the net return on the investment in human capital (i.e., after depreciation) must be equal to the net-return on financial saving:

$$BF'(I(t)H(t))\left(1 - \exp[((1-\tau_A)r+\delta)\,(t-R)]\right) - \delta = (1-\tau_A)r, \quad 0 \leq t \leq R. \tag{18}$$

Note that the labor tax does τ_L not affect the net return to human capital, since all opportunity costs and benefits from investments in human capital receive a completely symmetric tax treatment (Heckman, 1976). Note also that a higher tax on financial saving makes human capital investment more attractive by lowering the effective rate at which future wage increases are discounted, and by increasing the effective time-horizon of the individual.

3 Simulations

To gain more insight into the comparative dynamics of the model, we simulate it for a reasonable set of parameters. To that end, we need to put some structure on the utility function and the production function for human capital. We assume that utility is represented by relatively

standard CES sub-utility functions

$$\int_0^T \frac{C(t)^{1-1/\theta}}{1-1/\theta}\exp(-\rho t)dt + \gamma\frac{(T-R)^{1-1/\beta}}{1-1/\beta}, \quad \theta,\gamma,\beta > 0, \tag{19}$$

where θ, γ, and β denote the inter-temporal elasticity of substitution in consumption, a preference parameter for retirement and the retirement elasticity. The human capital production function is Cobb-Douglas

$$F(I(t)H(t)) = (I(t)H(t))^{\alpha}, \quad \alpha > 0, \tag{20}$$

where α is the constant elasticity of the human capital production function. The simulations use a discrete-time version of the model, which is derived in the appendix.

The time-span is set at 60 years, hence $T = 60$. We assume that individuals start working at age 20 so that individuals die at age 80. We thus ignore the initial education phase. A pure rate of time preference of $\rho = 0.025$ is chosen, which is fairly standard. The same is true for the real interest rate, which is set at $r = 0.05$. After an extensive review of the scarce empirical literature, Trostel (1993) sets the elasticity of the human capital production function at $\alpha = 0.6$. We employ the same value in our simulations. Furthermore, we set the depreciation rate of human capital at a relatively low value of $\delta = 0.02$. Indeed, most earnings profiles do not tend to level-off much at the end of the lifecycle, hence depreciation of human capital appears to be modest (Heckman et al., 1998).

In the appendix we demonstrate that the uncompensated elasticity of retirement – at constant levels of human capital – is given by $\frac{(T-R)}{R}\beta\left(1-\frac{1}{\theta}\right)$. Consequently, both the intertemporal elasticity of substitution θ and the retirement elasticity β jointly pin down the retirement elasticity. The estimates in Gruber and Wise (1999, 2002), OECD (2004), and Duval (2004) imply that the uncompensated elasticity of labor force participation of older workers with respect to the implicit tax on retirement (thus including wealth and income effects) is approximately one third. We employ a more conservative value of 0.2. Moreover, we need to assume an intertemporal elasticity of substitution in consumption θ larger than unity so as to find a positive uncompensated retirement elasticity. We have set it at $\theta = 1.25$ in our simulations. A value of $\theta = 1$ is often used in real business-cycle models, see e.g. Lucas (1990). Although the empirical estimates vary considerably, a value of $\theta = 0.5$ is suggested by most empirical microeconomic research, see for example Attanasio and Weber (1995). However, values of $\theta < 1$ imply backward bending 'retirement curves', which are clearly counter-factual. By setting $\theta = 1.25$ we obtain realistic retirement behavior and avoid too large wealth/income effects in retirement. Finally, a value of $\beta = 2$ pegs the uncompensated retirement elasticity at 0.2 at a calibrated retirement age of $R = 40$ (age 60) and a life-span of $T = 60$.

The baseline set of policy variables is $\tau_L = 0.5$, $\tau_A = 0.30$, and $\tau_R = 0.3$. These values match unweighted averages for a sample of 16 continental European and Anglo-Saxon countries (see also Jacobs, 2009). Total marginal tax wedges on labor income (including employer contributions and local taxes) are 51% for a single household without dependents which earns the average production wage (OECD, 2007). The effective marginal tax rate on capital income is harder to obtain given the large differences in tax treatments of various sources of capital

income in different countries (see for example Carey and Rabesona, 2004). For this moment we have set it at 30%. Gruber and Wise (1999), OECD (2004), and Duval (2004) show that the implicit tax on retirement amounts to around 30% for an older worker aged between 55–65, although there are substantial cross-country differences.[5]

The remaining parameters (W, B, and γ) are calibrated such that the individual retires at age 60 ($R = 40$), he invests 71% of his time at the start of his career in human capital (i.e., $I(0) = 0.71$) and the individual's gross labor earnings per year are 30.6 (thousand euro) on average during working-life. The calibrated values for the remaining parameters are: $W = 25.4$, $B = 0.09$, and $\gamma = 2.4$. Tax revenues are absorbed by the government to finance spending on public goods and are not rebated.[6]

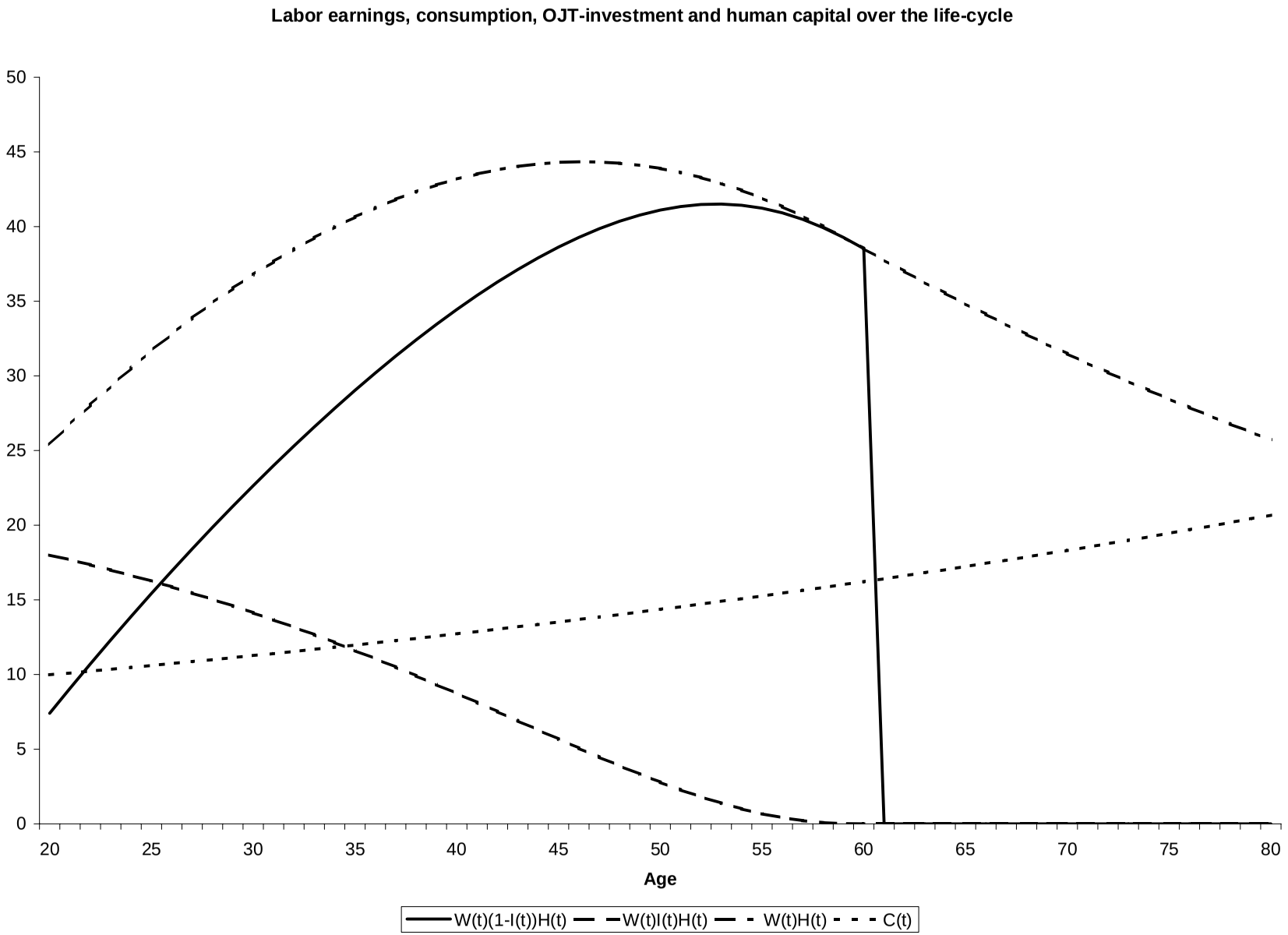
The baseline time-paths of consumption, the value of total investment in human capital ($WI(t)H(t)$), total labor earnings ($W(1 - I(t))H(t)$), and total human capital ($WH(t)$, scaled with rental rates) are plotted in Figure 1. Investment in human capital is high at the beginning of the working career, and declines monotonically until the retirement age is reached. The reason is that the payback time of investments continuously decreases. Hence, returns on investments fall over time. Indeed, labor earnings drop to zero at the retirement age of 60. The lifecycle profile of labor earnings steadily increases until it peaks at age 53 and then decreases slightly afterwards. This reflects both the investment in OJT before the peak and the depreciation of human capital after the peak. There would be no decline in labor earnings at the end of the lifecycle in the absence of depreciation of human capital. Also, the total value of the time endowment is plotted ($WH(t)$). This is a measure for total labor productivity, since rental rates are constant over time. It peaks at age 46, before the peak in earnings, cf. Ben-Porath (1967) and Heckman (1976). The intuition is that at age 46 individuals are still investing about 10% of their time endowment in OJT. Consequently, total labor productivity peaks earlier in the lifecycle than total earnings do. The individual also has a valuable time endowment after retirement, although it is steadily depreciating. Investment in human capital drops to zero at retirement, since the marginal value of investment in human capital has become zero at that date. Finally, the lifecycle path of consumption is increasing. The reason is that the net interest rate is larger than the pure rate of time-preference. Note that the consumption path is substantially lower than the earnings path, since the latter are denoted in gross terms (i.e., before 50% labor income taxes).

Interesting wealth dynamics emerge from our model, see Figure 2. Like in any lifecycle model, total wealth, defined as the present discounted value of remaining life-time financial and human wealth, declines first, and then rises somewhat until retirement, and then declines to zero at the end of life. In contrast to models with exogenous human capital, financial wealth drops to negative levels at the beginning of the lifecycle while the individual is investing in OJT. After age 33, the individual starts to save, and above age 47 the individual is debt free and financial wealth is accumulated for retirement. The evolution of financial wealth shows

[5] Gruber and Wise (1999) report the so-called 'tax force' statistic, which corresponds to the sum of marginal tax wedges on retirement while working during ages 55–69. Dividing the 'tax force' by 15 gives a yearly average marginal tax wedge on retirement during working ages 55–69. OECD (2004) computes marginal tax wedges on retirement which are around 20% (40%) on average for 55-59 (60-64) year old workers. Duval (2004, p.33) calculates that average implicit tax rates in OECD countries are equal to 30%.

[6] Implicitly, we assume that public goods enter in a completely separable fashion in the utility function.

Figure 1:


Labor earnings, consumption, OJT-investment and human capital over the life-cycle
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35
40
45
50
55
60
65
70
75
80
Age
W(t)(1-I(t))H(t)
W(t)I(t)H(t)
W(t)H(t)
C(t)

that capital markets to smooth consumption over the lifecycle could be important, although borrowing is not that large at the beginning of the lifecycle. Indeed, most of the financial wealth is accumulated after age 45 to finance consumption during the retirement phase. The evolution of human wealth partially mirrors the evolution of financial wealth. Human wealth steadily decreases while working as the remaining life-time earnings diminish. At the moment of retirement, human wealth only consists of the remaining present value of retirement benefits, and would be zero in the absence of them.

Figure 3 plots the simulated patterns of OJT-investment and lifecycle earnings for different values of the labor tax rate and the capital tax rate. Lifecycle investments in OJT are affected by the labor tax rate through its impact on retirement only (recall that all costs of OJT are deductible). Since retirement is distorted by the presence of the implicit tax τ_R, a higher explicit tax on retirement τ_L reduces OJT-investments to a considerable extent, since the payback period of investment in human capital falls substantially. As a result, lifecycle earnings profiles shift towards the origin. As OJT-investments fall, the peak of earnings will be earlier. Moreover, since less time will be invested in OJT, earnings when young increase slightly. However, at later ages this is more than offset by lower stocks of human capital so that earnings declines. This, in turn, makes earlier retirement more attractive as the opportunity costs of retirement are lower when wages in the last year working are lower. This graph indirectly shows that policies which stimulate earlier retirement, can have important consequences for OJT investments. We return to this below.

A higher capital tax boosts investments in human capital, since saving becomes less attractive compared to investment in OJT. Again, we see earnings-profiles rotate as under the labor tax, but now in the reverse direction. Especially at the beginning of working careers, OJT-investment increases, hence total gross labor earnings fall. Over time, however, this fall in earnings will be compensated by rising levels of human capital, which result in increasing labor earnings at later ages. The peak in the earnings profile shifts to later ages and individuals end their working careers with substantially higher earnings. This graph demonstrates the fundamental interactions between saving policies and OJT-investments. Indeed, human capital investments can be seriously affected if governments want to boost saving by lowering the capital tax (or even give tax-incentives for saving). Consequently, OJT-policies cannot be seen in isolation from pension and saving policies.

Figure 4 plots the investment and earnings profiles for various implicit tax rates on retirement and depreciation rates of human capital. A higher implicit tax on retirement τ_P, much like the labor tax, gives stronger incentives to retire early from the labor market. Indeed, investment in human capital falls during all ages. This increases earnings temporarily as workers have higher labor earnings at the beginning of the lifecycle, but their wage growth over the lifecycle will be substantially lower. Since less human capital will be accumulated, workers end up with lower wages at the end of their careers. This makes retirement also more attractive as the opportunity costs of retirement have fallen. Thus, when retirement schemes are actuarially very unfair, and thereby cause large distortions on retirement, this seriously impairs investments in OJT too. As a result, our theoretical model confirms the notion that individuals do not invest in skills because they retire early, and they retire early because they do not invest in skills.

Figure 2:

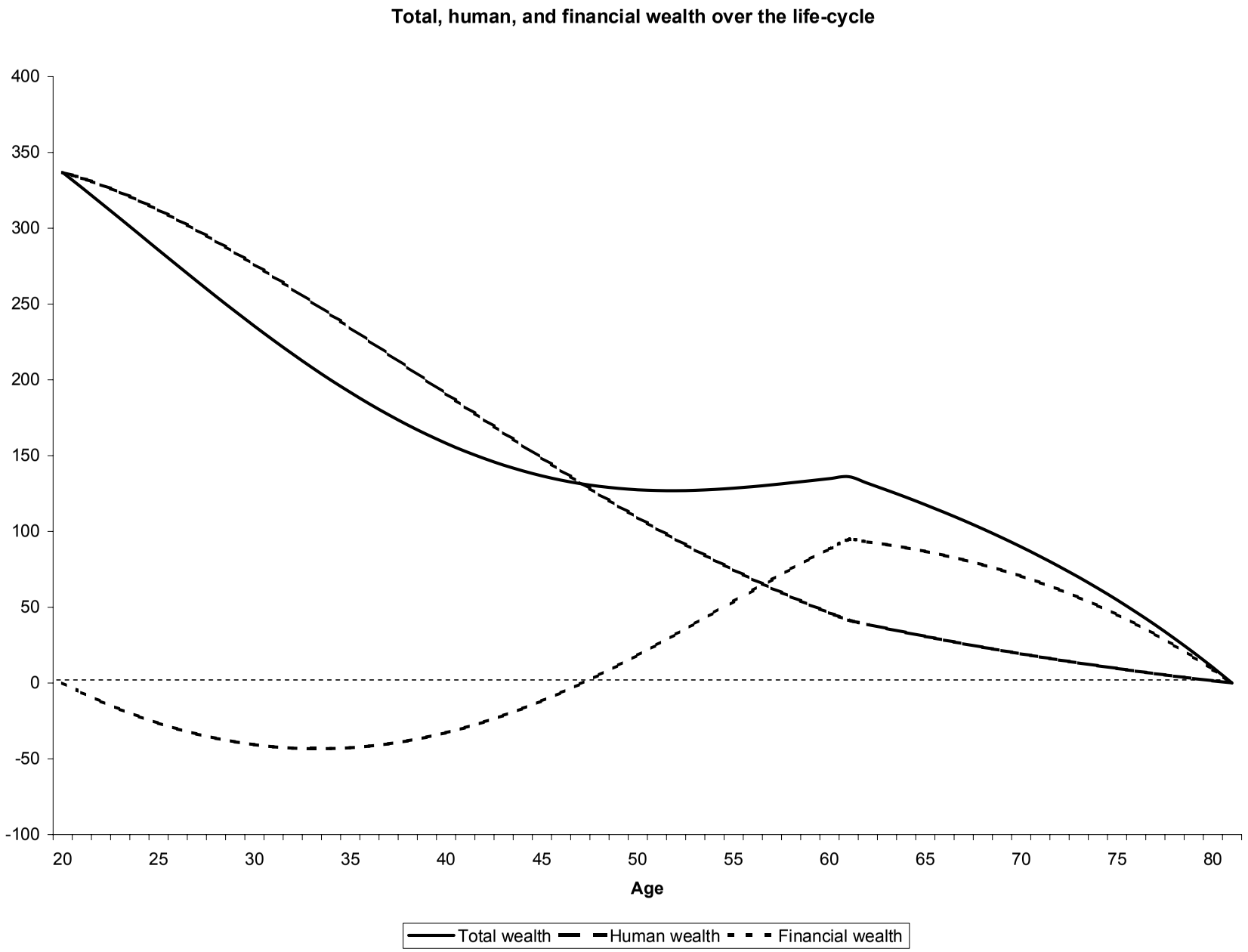
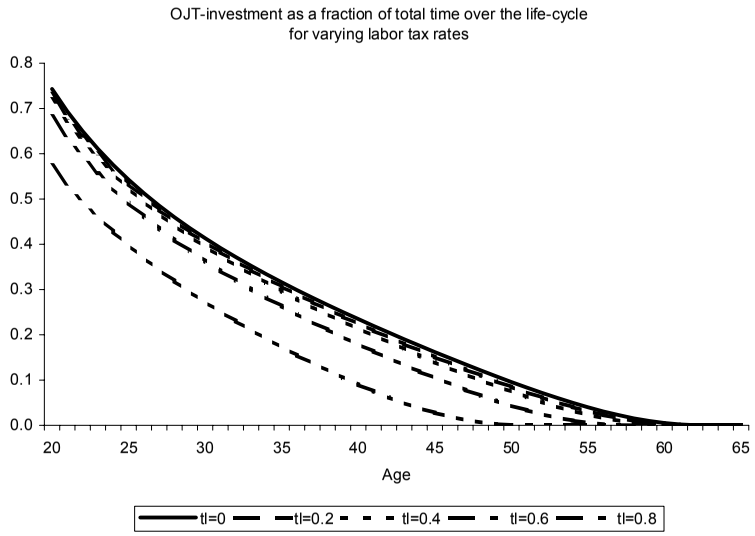
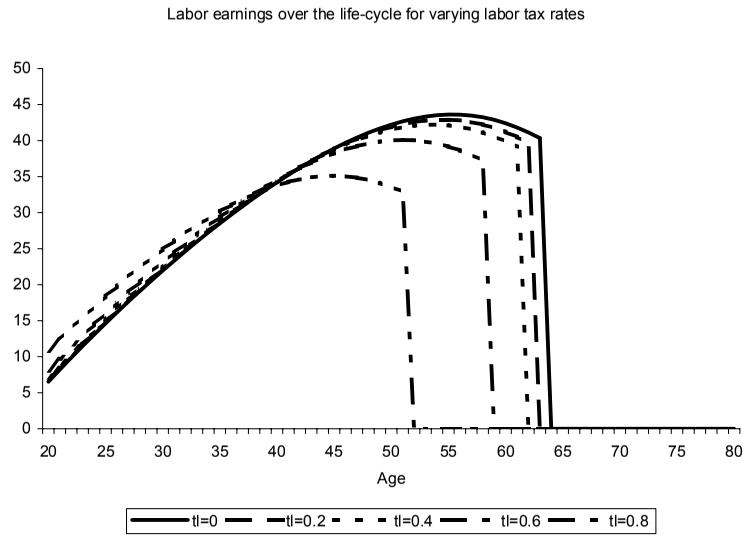
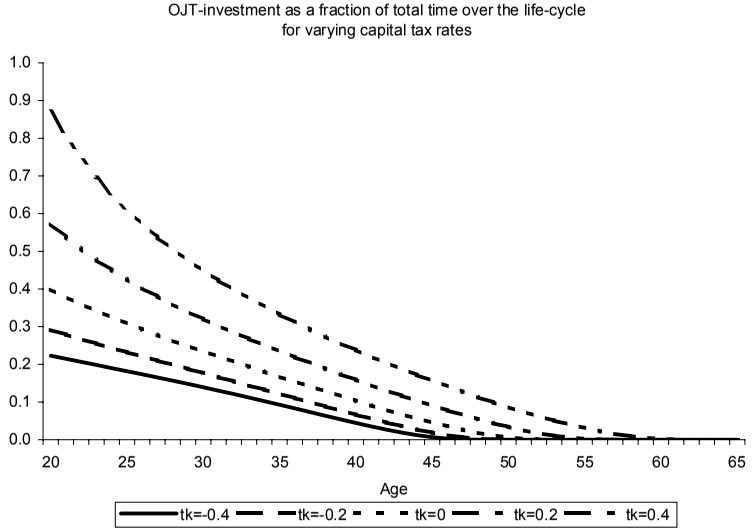

Total, human, and financial wealth over the life-cycle
400
350
300
250
200
150
100
50
0
-50
-100
20
25
30
35
40
45
50
55
60
65
70
75
80
Age
Total wealth
Human wealth
Financial wealth

Figure 3:


OJT-investment as a fraction of total time over the life-cycle
for varying labor tax rates
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
20 25 30 35 40 45 50 55 60 65
Age
tl=0 tl=0.2 tl=0.4 tl=0.6 tl=0.8


Labor earnings over the life-cycle for varying labor tax rates
50
45
40
35
30
25
20
15
10
5
0
20 25 30 35 40 45 50 55 60 65 70 75 80
Age
tl=0 tl=0.2 tl=0.4 tl=0.6 tl=0.8


OJT-investment as a fraction of total time over the life-cycle
for varying capital tax rates
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
20 25 30 35 40 45 50 55 60 65
Age
tk=-0.4 tk=-0.2 tk=0 tk=0.2 tk=0.4

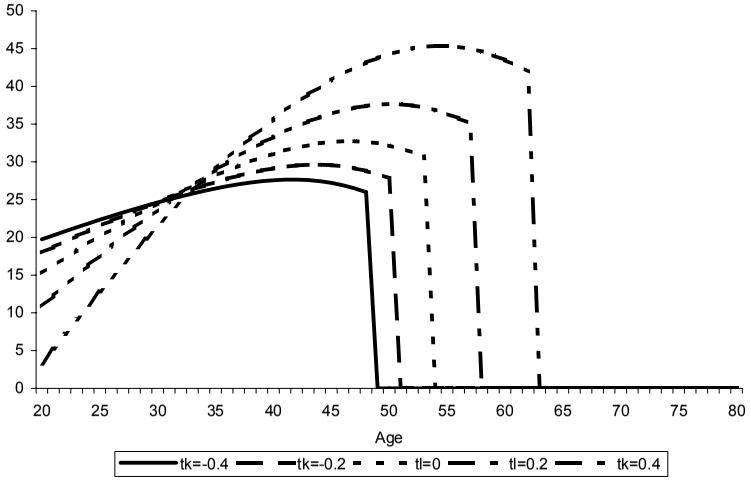
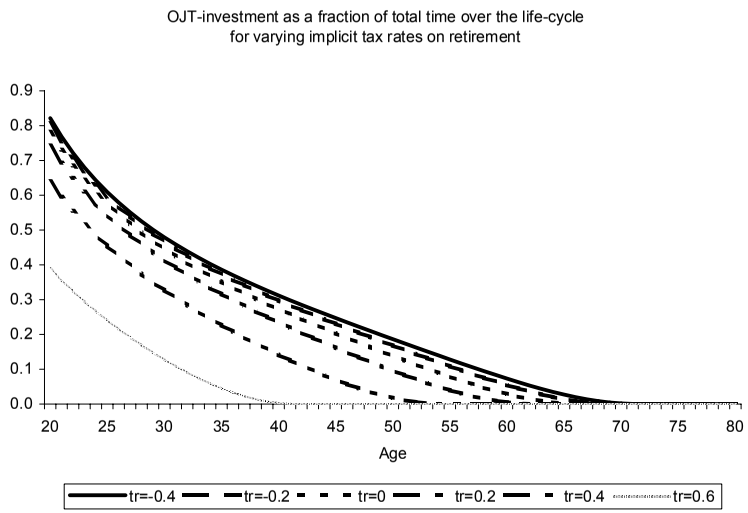
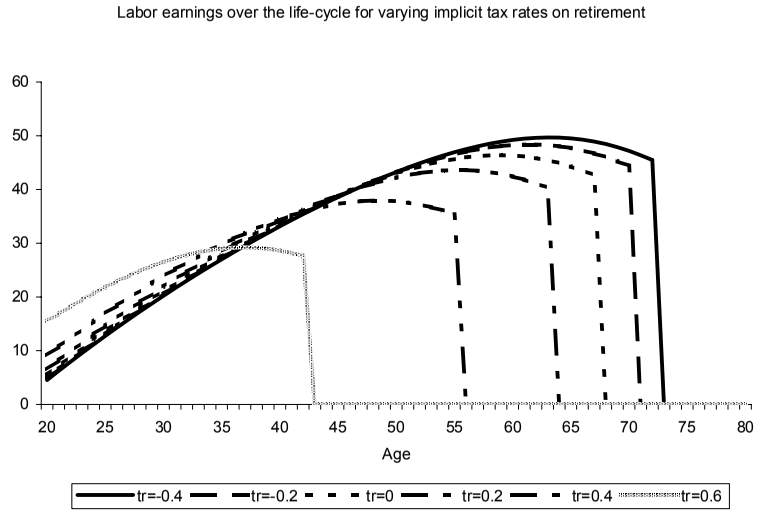
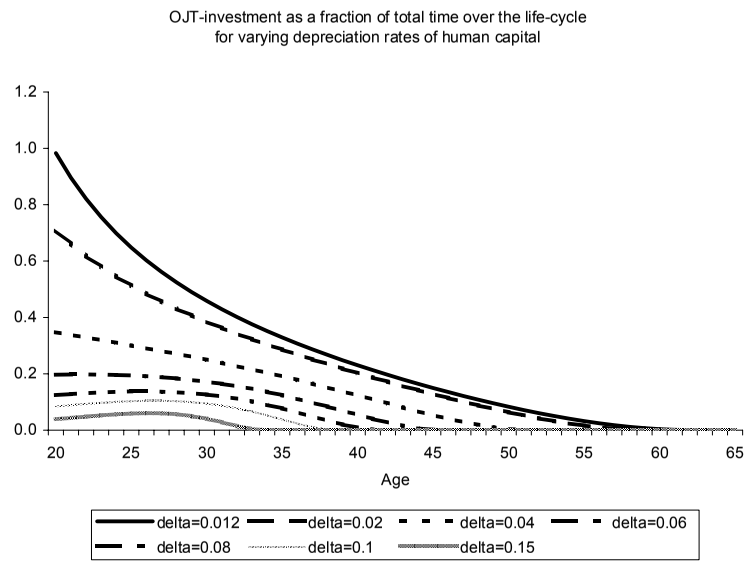
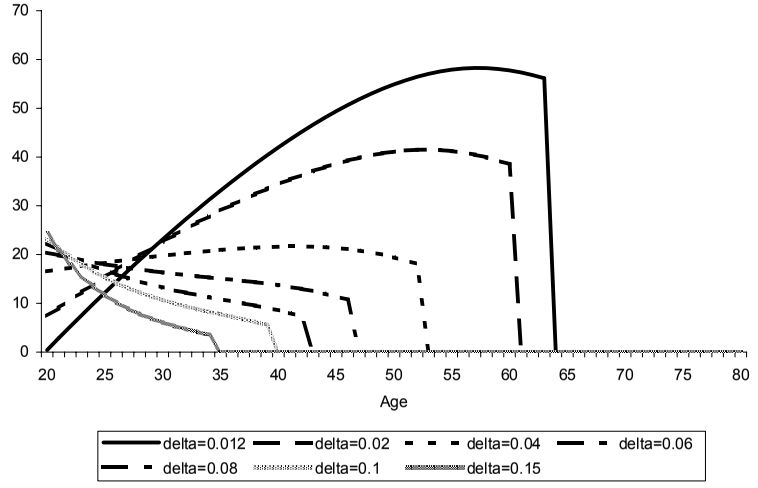

Labor earnings over the life-cycle for varying capital tax rates
50
45
40
35
30
25
20
15
10
5
0
20 25 30 35 40 45 50 55 60 65 70 75 80
Age
tk=-0.4 tk=-0.2 tl=0 tl=0.2 tk=0.4

Figure 4:


OJT-investment as a fraction of total time over the life-cycle
for varying implicit tax rates on retirement
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
20 25 30 35 40 45 50 55 60 65 70 75 80
Age
tr=-0.4 tr=-0.2 tr=0 tr=0.2 tr=0.4 tr=0.6


Labor earnings over the life-cycle for varying implicit tax rates on retirement
60
50
40
30
20
10
0
20 25 30 35 40 45 50 55 60 65 70 75 80
Age
tr=-0.4 tr=-0.2 tr=0 tr=0.2 tr=0.4 tr=0.6


OJT-investment as a fraction of total time over the life-cycle
for varying depreciation rates of human capital
1.2
1.0
0.8
0.6
0.4
0.2
0.0
20 25 30 35 40 45 50 55 60 65
Age
delta=0.012 delta=0.02 delta=0.04 delta=0.06
delta=0.08 delta=0.1 delta=0.15

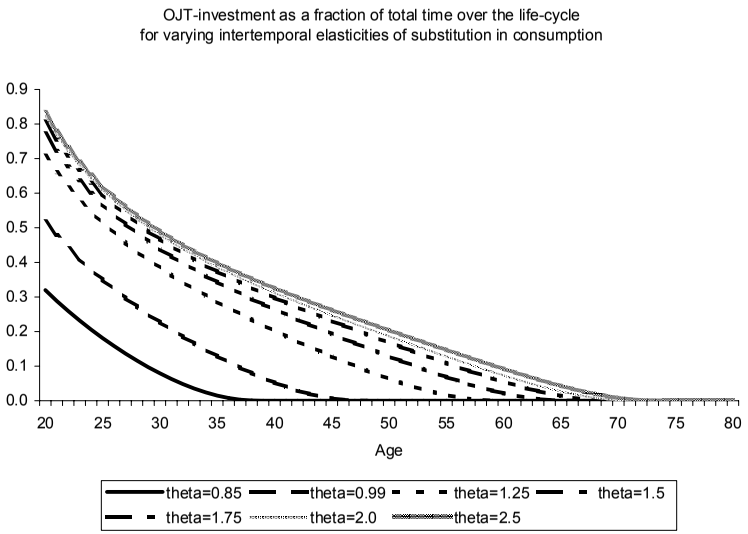

Labor earnings over the life-cycle for varying depreciation rates of human capital
70
60
50
40
30
20
10
0
20 25 30 35 40 45 50 55 60 65 70 75 80
Age
delta=0.012 delta=0.02 delta=0.04 delta=0.06
delta=0.08 delta=0.1 delta=0.15

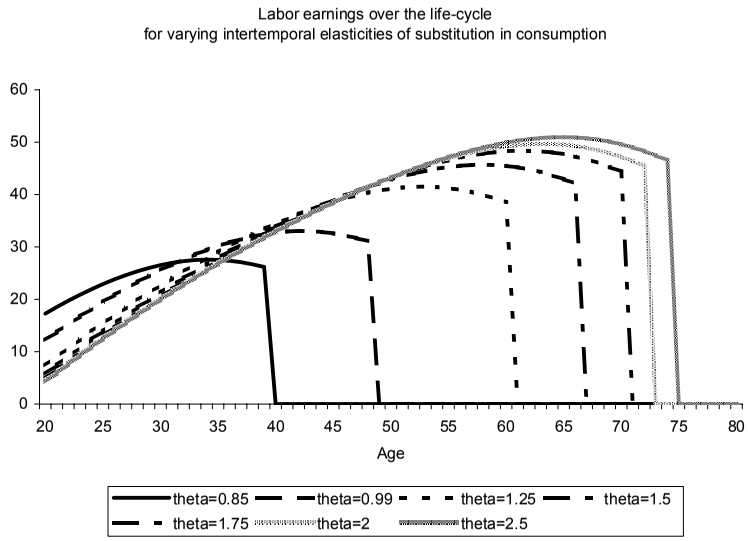
A larger rate of depreciation of human capital has similar effects as a higher implicit tax on retirement, only the consequences of higher depreciation rates are more severe. Indeed, the higher depreciation rate makes saving in financial capital relatively more attractive at all times, hence investments in human capital decrease throughout the lifecycle. Indeed, at relatively modest depreciation rates (5% and higher), earnings profiles even become downward sloping over the lifecycle. The reason is that the depreciation rate has become larger than the real interest rate, so that human capital decumulation has become optimal.

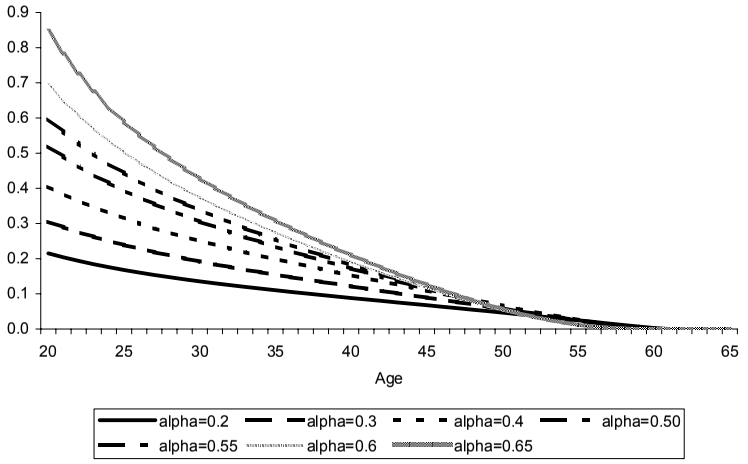
The messages from the retirement-augmented Ben-Porath model are clear-cut and simple. Investment in OJT shifts the wage profiles upwards, which implies that there are positive returns to OJT-investments. Investment in OJT increases if the retirement date increases (lower explicit and implicit taxes on retirement), if the opportunity return on saving decreases (higher capital taxes), and if the depreciation rate is lower. The lifecycle earnings profile is typically 'hump-shaped'. Moreover, policies that boost investment in human capital depress earnings at the beginning of the lifecycle and boost earnings at later ages. This is because the cost of investment is forgone working time. The model finally demonstrates that the policy environment is critical to understand lifecycle patterns in OJT-investment, labor earnings, retirement ages and savings behavior. Indeed, financial saving and human capital investments are substitutes, whereas retirement and human capital investments are complements.

Although the parameters of the model are not completely unrealistic, we still should be careful in drawing quantitative conclusions. All simulations are driven by the particular assumptions on the intertemporal elasticity of substitution in consumption θ, the elasticity of the human capital production function α, and the retirement elasticity β. Figures 5 and 6 provide some sensitivity analyses on the main elasticities of the model. The consumption and retirement elasticities are indeed important for retirement choices. Slight differences in both parameters give quantitatively large impacts on the retirement decision. This is in main part driven by the severe distortions in retirement choices. Indeed, the total tax wedge on retirement equals $1-(1-\tau_L)(1-\tau_R)=0.65$. Consequently, relatively small changes in elasticities have large impacts on retirement choices. The impacts on retirement choices should therefore be handled with care, given the relatively high value of θ we assumed in the base-line simulations so as to avoid backward-bending retirement curves. Not surprisingly, the elasticity of the human capital production function determines to an important extent the behavioral response of OJT-investments over the lifecycle. However, the lifecycle profile of wages is not so much affected. It only flattens out a bit over time as α increases. Note that we could not increase α a lot, since the non-negativity constraint on working time would then become binding. Finally, we simulated the model for different productivity levels of human capital B. We find that a higher productivity in OJT-investments (e.g. due to more initial education) unambiguously raises later OJT-investments. Initial earnings fall because individuals with a larger B spend a larger fraction of time to human capital investment, but earnings at later stages of the lifecycle increase as a result of more human capital accumulation.

Figure 5:


OJT-investment as a fraction of total time over the life-cycle
for varying intertemporal elasticities of substitution in consumption
Age
theta=0.85
theta=0.99
theta=1.25
theta=1.5
theta=1.75
theta=2.0
theta=2.5


Labor earnings over the life-cycle
for varying intertemporal elasticities of substitution in consumption
Age
theta=0.85
theta=0.99
theta=1.25
theta=1.5
theta=1.75
theta=2
theta=2.5


OJT-investment as a fraction of total time over the life-cycle
for varying elasticities of human capital
Age
alpha=0.2
alpha=0.3
alpha=0.4
alpha=0.50
alpha=0.55
alpha=0.6
alpha=0.65

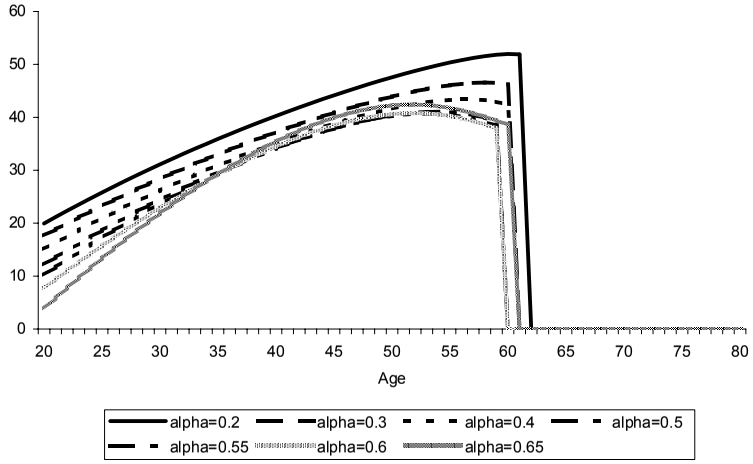
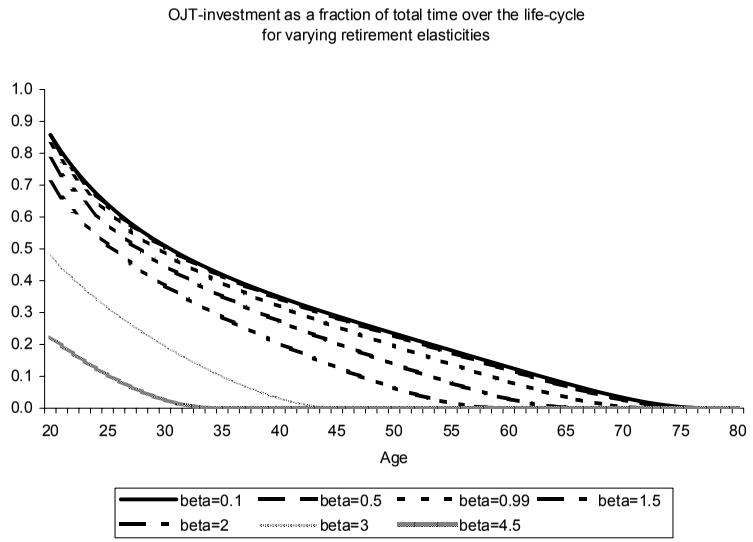
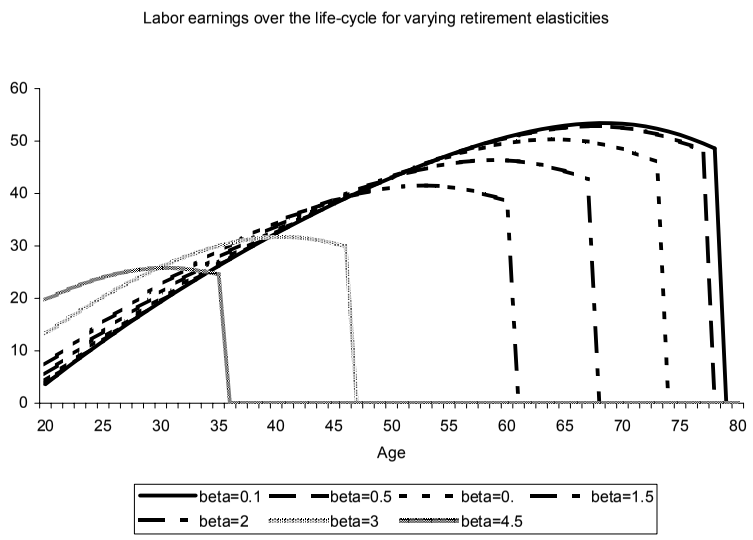
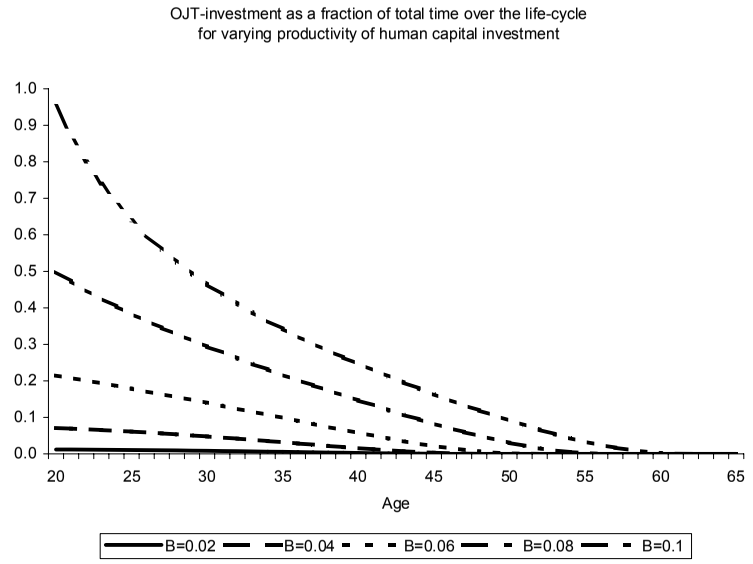
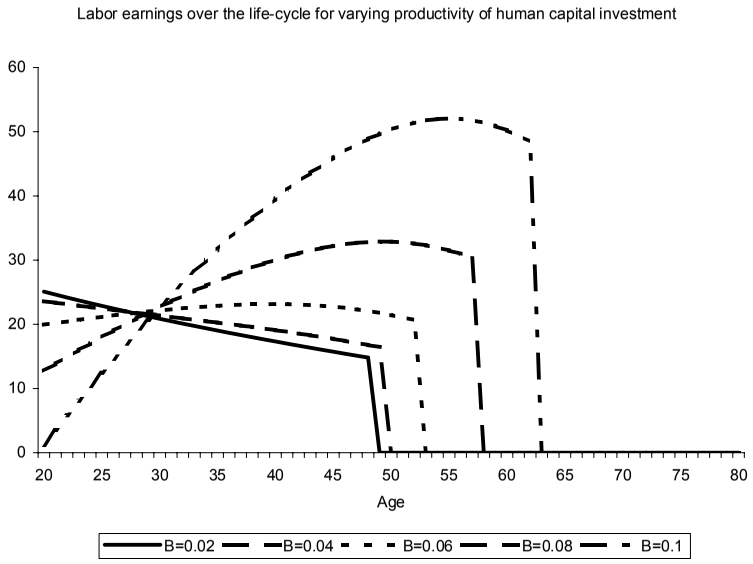

Labor earnings over the life-cycle for varying elasticities of human capital
Age
alpha=0.2
alpha=0.3
alpha=0.4
alpha=0.5
alpha=0.55
alpha=0.6
alpha=0.65

Figure 6:


OJT-investment as a fraction of total time over the life-cycle
for varying retirement elasticities
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
20 25 30 35 40 45 50 55 60 65 70 75 80
Age
beta=0.1
beta=0.5
beta=0.99
beta=1.5
beta=2
beta=3
beta=4.5


Labor earnings over the life-cycle for varying retirement elasticities
60
50
40
30
20
10
0
20 25 30 35 40 45 50 55 60 65 70 75 80
Age
beta=0.1
beta=0.5
beta=0.
beta=1.5
beta=2
beta=3
beta=4.5


OJT-investment as a fraction of total time over the life-cycle
for varying productivity of human capital investment
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
20 25 30 35 40 45 50 55 60 65
Age
B=0.02
B=0.04
B=0.06
B=0.08
B=0.1


Labor earnings over the life-cycle for varying productivity of human capital investment
60
50
40
30
20
10
0
20 25 30 35 40 45 50 55 60 65 70 75 80
Age
B=0.02
B=0.04
B=0.06
B=0.08
B=0.1

4 Empirical content of the model

The previous section provided a parsimonious theoretical model of investment in human capital, saving, and retirement. The model contained a number of empirically testable implications:

- Earnings follow a 'hump' shape, and labor productivity peaks before earnings;
- Investment in human capital decreases with age;
- Investment in training increases if productivity of training is larger, e.g. due to larger investment in initial education;
- Retirement ages decrease with the implicit or explicit tax rate on continued work, which in turn reduces OJT;
- (Retirement) savings decrease with a larger tax on savings, which in turn boosts OJT.

In the remainder of this section we argue that the empirical evidence is in line with the stylized features of the model. However, a number of implications have not been derived empirically.

4.1 Earnings-profiles and OJT

Age-earnings profiles ($W(1-I(t))H(t)$) are indeed hump-shaped, which follows from the commonly estimated Mincer wage-equation with experience (age) and experience squared (age squared) (see e.g. Card, 1999).

Direct measurements of productivity over the lifecycle ($WH(t)$) are indeed quite suggestive of a hump-shaped pattern of productivity of the lifecycle as well. Note, again, that productivity does not equal labor earnings, because of investments in training $I(t)$. Skirbekk (2005) surveys the literature and finds the following stylized facts. Cognitive abilities decline after some stage in adulthood. Older workers compensate withering cognitive skills with sufficient working experience (for example by OJT or learning-by-doing). Based on subjective evaluations of managers, age-productivity profiles do not seem to display systematic patterns. Evaluations by workers suggest that worker's productivity indeed falls with age. Objective evaluations (based on measured outputs) suggests that quantity and quality of output show a hump-shaped pattern with age. Importantly, Skirbekk (2005) also presents empirical evidence that labor productivity measures peak before labor earnings, which is theoretically predicted by our model as well.

However, from the hump-shaped pattern of earnings one cannot conclude that they are *caused* by investments in OJT. Indeed, other theories of wage determination over the lifecycle could be relevant too (deferred payments, learning by doing, wage setting institutions, etc.). Skirbekk (2005) resorts to Lazear's (1976) theory of deferred payments to explain the earnings-profiles. This theory will be discussed later in more detail as well.

Direct estimates of the effect of training activities on wages generally give positive wage returns (Leuven, 2005; Bassanini et al., 2006). Allocating time to training activities is correlated with rising wages over the lifecycle. However, the empirical evidence also seems fragile due to selectivity problems in the estimations (Leuven, 2005; Bassanini et al., 2006). Moreover, some serious measurement issues prevent drawing strong conclusions, see below.

4.2 Time-horizon and complementarity with initial education and OJT

Given the finite horizon (T), younger workers are expected to participate more in training. Furthermore, better educated workers (higher B) are also expected to invest more in training, since training increases with the productivity of training activities. Both are indeed found to be stylized facts in the data (Leuven, 2005; Bassanini et al., 2006).

4.3 Participation and OJT

Another stylized fact is that male workers have higher participation rates in training than female workers. One obvious explanation is that men work more hours and have higher labor participation. Consequently, their 'utilization rates' of OJT human capital are higher. Given that our model does not allow for an endogenous work/participation decision, we miss this feature. However, Heckman and Jacobs (2006) extend a similar model with endogenous labor supply and find that workers with less labor supply utilize their human capital less and therefore invest less in OJT. Women could be outside the labor market because they invest more in the human capital of children, which is something that we abstracted from.

4.4 Retirement and OJT

Gruber and Wise (1999) show that labor force attachment of the average worker is rapidly declining with age. Many workers retire long before statutory retirement ages via all kinds of early-retirement schemes. Pension benefits can be generous as well. Pension replacement incomes in Continental European are quite high and about 60-80% of pre-retirement earnings for an average worker (OECD, 2005). Pension systems are PAYG state pensions almost everywhere. Exceptions are the Anglo-Saxon countries, the Netherlands, Sweden and Denmark that also heavily rely on substantial private funding, either through DB/DC occupational pensions or individual saving schemes see also OECD (2005). It is not easy to make international comparisons because the institutional details vary from country to country. Gruber and Wise (1999) summarize the impact of early retirement schemes on the labor market by the implicit marginal tax rates imposed on an additional year of work (our τ_R). Duval (2004) and OECD (2004) demonstrate that early retirement schemes do indeed cause very high marginal tax rates on pre-retirement incomes. Moreover retirement ages and benefit generosity are very negatively related. Gruber and Wise (1999, 2002) present strong evidence that this is a causal relation. In recent years some countries have attempted to reform their pension schemes. The Netherlands, Germany, France, and Italy are examples.

Bassanini et al. (2006) do a simple cross-country panel analysis, which suggests that investments OJT and later retirement are indeed positively correlated. This is consistent with our findings. Moreover, skilled workers typically retire much later than unskilled workers (OECD, 2006). Since education and training are complementary activities, this should come as no surprise either.

4.5 Pensions

Not much is known about the impact of saving or pension policies (τ_A) on the incentives for OJT-investments. As of today, there appears to be no empirical evidence that directly estimates the impact of saving and pension policies on OJT-investment. At least theoretically, saving and investing in human capital are substitutes *for a given level* of overall, i.e., human and financial, saving. Hence, a higher tax rate on financial saving, tends to boost human capital investments. However, also the level of saving can be affected by taxes on savings, depending on off-setting income and substitution effects. Clearly, tax incentives are important for financial saving decisions (see e.g. Bernheim, 2002). In the earlier empirical literature, only small effects of tax incentives on saving were found. On balance, however, most recent empirical evidence clearly points to a dominant substitution effect in saving (Bernheim, 2002).

5 Theoretical, empirical and methodological issues

Is the model presented above the correct model to analyze the interactions between human capital, retirement and pensions? We don't know for various reasons. First of all, the model made a number of important assumptions, which may not be warranted from an empirical point of view. Second, maybe the standard human capital model is not the right model to capture lifecycle earnings. Various competing theories are available. Third, both measurement and methodological problems prevent the direct testing of the model. These issues will now be discussed in more detail.

5.1 Modeling assumptions

In our view, the most important modeling assumptions are the following

- Perfectly competitive labor markets: wage rate per unit of skill are constant and equal to productivity per unit of skill;
- Lifecycle earnings profiles driven by investments in human capital;
- Perfect capital markets: all assets are liquid, borrowing and lending at common risk-free rate is possible;
- Perfect insurance markets: there is no risk/uncertainty, and life-expectancy is certain;
- No heterogeneity: there is no difference in abilities and lifespans;
- Rational expectations, individuals are blessed with perfect foresight: there is no myopia, no hyperbolic discounting, etc.

The next subsection is entirely devoted to a discussion of the assumption of perfectly clearing labor markets. This is in our view the most important assumption made so far, and will be discussed extensively below. Further, we will discuss various competing theories that can also explain observed patterns in the data. We now shortly discuss the other assumptions.

5.1.1 Capital market failure

Naturally, capital markets can fail and not all assets are perfectly liquid. Illiquid housing wealth is an example which represents a large fraction of total financial wealth in household portfolio's in most Western countries. Moreover, individuals can be borrowing-constrained. In some countries, such as the Netherlands, individuals are obliged to save for retirement in collective labor agreements, even if they do not want to. This also generates borrowing constraints if individuals cannot collateralize their pension wealth. Both liquidity and borrowing constraints can in theory impede socially desirable investments in human capital.

From the microeconometric literature, there is ample empirical evidence that borrowing constraints could be important for consumption choices (see for example Hall and Mishkin, 1982; Hayashi, 1985; Mariger, 1987; Zeldes, 1989; Attanasio, 1995; Browning and Lusardi, 1996; and Blundell, 1988). Empirically, direct evidence of borrowing constraints on investments in training on-the-job is missing, see also Bassanini et al. (2006). The prime reason is that both costs and returns are hard to verify for the analyst, an important issue to which we will return below. A large literature identifying the role of liquidity and borrowing constraints for initial education only finds small effects for the lower end of the income distribution, see for example Carneiro and Heckman (2003), Cunha et al. (2006), and the studies they cite. Therefore, we are tempted to conclude that borrowing constraints should probably not be the first focus for future research. Indeed, in our model simulations savings are mainly made to save for retirement, see figure 2. Hence, if our model is only roughly plausible, binding borrowing constraints are expected to affect the results for training, but probably not to a very large quantitative extent.

5.1.2 Risk and uncertainty

We also abstracted from non-insurable risk and uncertainty, thereby ruling out any precautionary savings or any effects of risk on human capital investments. Browning and Lusardi (1996) argue that especially precautionary saving is an empirically important component of household's financial savings.

How risk affects human capital investment is critically determined by the ways in which human capital affects the risk to which individuals are exposed (Jacobs et al., 2008). If human capital investment increases risk in labor earnings, risk-averse individuals will underinvest so as to reduce their exposure to risk. However, if human capital investment reduces the exposure to risk, the opposite holds true, i.e., risk-averse individuals will overinvest (see also Levhari and Weiss, 1974). Empirically, little is known about the risk-properties of human capital, see also Jacobs (2007) and Jacobs et al. (2008), and the references mentioned there. Indeed, better skilled individuals seem to have both a larger variance in earnings and a lower incidence of unemployment, sickness and disability. Moreover, better skilled individuals participate more and retire much later. Consequently, investment in human capital can both increase and decrease earnings risk.

According to the knowledge of the author there is neither theory nor empirical research available that simultaneously addresses uncertainty in human capital returns and risky returns on savings. Note that labor earnings do not directly measure the marginal return to investing one unit of resources in human capital. Therefore, it is not clear how returns to human capital covary

with the returns on risky assets, and how the covariance structure changes over the lifecycle. We think that allowing for uncertainty is potentially an important avenue for future research, especially when it comes to understanding financial planning, skill maintenance, and, retirement and pension choices. However, a thorough analysis of risk in lifecycle settings with endogenous human capital formation requires much more advanced theory and empirical research.

5.1.3 Heterogeneity and distributional issues

This paper completely abstracts from distributional issues and is focused on a positive analysis of understanding the behavioral interactions between OJT, pension saving, and retirement. We have shown that promoting pension saving or introducing early retirement schemes may have (unintended) adverse consequences for investments in human capital. However, this does not imply that these policies are socially undesirable. Naturally, many public policies could be justified by distributional concerns. For example, it may well be worthwhile to introduce distortions in retirement choices if this helps to redistribute resources to the lifetime poor, who have been born with a low ability or have been hit by adverse skill shocks during the lifecycle (Bovenberg and Jacobs, 2009). We believe that this applies more generally. Heterogeneity and finite lives renders the taxation of labor income optimal (Mirrlees, 1971) and could also make taxation of capital income optimal (Jacobs and Bovenberg, 2008). However, the implications of lifecycle considerations for the optimal setting of tax rates on labor or capital income over the lifecycle are not yet fully crystallized (Diamond and Banks, 2009).

Two other potentially important sources of heterogeneity could originate from differences in depreciation rates for human capital or differences in life-expectancy. Both are fixed in the model. However, typically less-skilled individuals seem to have higher depreciation rates of human capital (due to physically more demanding jobs) and have a lower life-expectancy (due to more unhealthy life-styles). Perhaps, a high life-expectancy can also be viewed as the result of investment in human capital, i.e., investment in health. Future research should dwell upon these issues in more detail.

5.1.4 Rational and forward looking behavior

Like any lifecycle model, also our model heavily rests on the forward looking and rational behavior of households. Recent developments in behavioral economics have pointed to the weaknesses of this traditional framework to analyze saving and investment decisions over long time-horizons, especially when it comes to retirement and pension decisions. We believe that many of the arguments brought forward in the behavioral economics literature also apply to investment in human capital over the lifecycle. However, we are unaware of applications to investments in training. For sure, concepts from behavioral economics can be fruitfully applied in this area.

5.2 Imperfectly competitive labor markets and alternative theories for lifecycle earnings

The most important assumption in the model discussed in the paper is that the labor market is perfectly competitive and frictionless. We assumed that the rental rate W is equal to the productivity per efficiency unit of human capital.[7] However, a perfectly competitive labor market is probably not a valid approximation for many European labor markets that are characterized by all sorts of frictions, institutions, and government interventions. In non-competitive labor markets, the theoretical connection between the productivity per efficiency unit of human capital and the price per efficiency unit of human capital is generally lost. Wages, or more precisely, rental prices per unit of human capital do then not purely reflect productivity, but also market frictions. Moreover, the rental rates do not need to be constant over the lifecycle.

In addition, we assumed that the Ben-Porath (1967) human capital model is the correct explanation for the lifecycle earnings patterns we observe in the data. Nevertheless, other theories can also explain why earnings profiles are hump-shaped. Some of these alternative theories are directly tied to frictions in the labor market. Therefore, we decided to discuss them in this section as well. The main message of this section is that understanding the working of the labor market is key to understand the interactions between training, saving, and retirement.

5.2.1 Minimum wages

A wage floor in an otherwise competitive labor market destroys employment for all workers with labor productivity below the wage floor. This results in involuntary unemployment among these workers. Wage floors increase the wages of unskilled workers relative to skilled workers. Consequently, incentives to invest in OJT diminish. In addition, the employment probabilities of low skilled workers diminish and incentives to become skilled improve. Minimum wages may also generate general equilibrium effects on the wage structure by changing relative supplies of workers (Teulings, 2003). Hence, the effect of wage floors on skill formation is ambiguous.

5.2.2 Unions, efficiency wages, frictions, and insiders-outsiders

In a wide class of models with unions, efficiency wages, search frictions or insider-outsider problems, equilibrium wages are typically characterized by a mark-up equation relating the equilibrium wage to the outside options of workers, see Booth (1995), Mortensen and Pissarides (1999), Akerlof and Yellen (1986), and Lindbeck and Snower (1998, 2002). Equilibrium unemployment results because wages are pushed above the market clearing level. The wage mark-up generally increases with a larger bargaining power of workers, a lower elasticity of labor demand, a higher replacement rate, lower marginal and higher average income tax rates, higher firing costs, and better employment protection. See Layard et al. (1991), Pissarides (1998), Sørensen (1999), Lindbeck and Snower (2002), Bovenberg (2006), and Van der Ploeg (2006), and others.

[7] In addition, workers with different vintages of OJT human capital are perfect substitutes in production, so that rental rates per unit of human capital are equalized across all individuals with different levels of OJT human capital. At first sight, it would seem implausible that this would indeed be the case. However, any empirical evidence on these matters is currently lacking.

Labor market frictions will not only have static effects, but also affect the wage structure over the lifecycle. Employment protection legislation typically protects the older workers better than the younger workers. Labor turnover costs increase with workers' experience due to higher firing costs, stricter employment protection legislation, seniority rules ('last in, first out'), and other terms of employment. Older workers may have more bargaining power than younger workers, which is relevant for labor markets with unions, search-frictions, and insider-outsider problems. Typically, entitlements to social benefits increase with work experience and with income. Hence, outside options become more valuable as workers get older. All theories on non-competitive labor markets (unions, search frictions, efficiency wages, insiders-outsiders) then imply that wages are pushed more above market clearing levels as workers age. The actual design of labor market policies, tax systems, and social benefits is therefore critical in understanding how the outside options of workers are affected over the lifecycle (see Bovenberg and Van der Ploeg, 1994). Most analyses in the training literature pay insufficient attention to the tax treatment of both earnings and outside options, how entitlements to benefits are built up over time, and whether benefits are related to final earnings, and so on.

5.2.3 Worker incentives

The wage profile rotates as well in Lazear's (1976, 1979, 1981) incentive theories of deferred payments, mandatory retirement, and hours-restrictions. By changing the earnings over the lifecycle, the firm can provide incentives to workers if workers' productivity levels cannot be observed by the firm. Typically, an optimal contract features lower wages than labor productivity at the beginning of the lifecycle and higher wages than labor productivity at the end of the lifecycle. As such, also incentive issues can explain a hump-shaped pattern of earnings. Given the above market-equilibrium wage at the end of the lifecycle it is optimal to have mandatory retirement (Lazear, 1979). And, given that wages are not constant across years, it is optimal to have hours restrictions to avoid welfare losses of distortions in labor supply (Lazear, 1981).

5.2.4 Effect of non-competitive wage-setting on OJT

One might be tempted to conclude that in non-competitive labor markets, investments in OJT will be reduced as wages (the main cost of the investment) will be driven above market-clearing levels. Hence, investing in human capital becomes less attractive. However, also here some individuals will be priced out of the labor market and become unemployed/inactive. Employment rates are indeed much higher among the better skilled workers and better skilled individuals retire much later (OECD, 2006). Therefore, investment in OJT might also be boosted in non-competitive labor markets if workers want to lower the probability of becoming unemployed or inactive. As a result the impact of labor market institutions on OJT appears to be ambiguous from a theoretical perspective.

If the wage profile indeed tilts in favor of older workers, due to labor market frictions, institutions, or deferred payment schemes, the incentives to invest in schooling and training can be considerably affected. Older workers face weaker incentives to maintain skills and will invest less in second careers because the opportunity costs of doing so increase. The younger workers, on the other hand, have stronger incentives to invest in their careers early. The tilting of the

wage profile can promote steeper depreciation of human capital over the lifecycle. Incentives to retire early increase and employment rates of older workers decrease. See also the model simulations in the previous section. This is not necessarily efficient, and may be costly in terms of labor supply. As a corollary to Lazear (1979, 1981) binding limits on training for younger workers and forced OJT programs for older workers could be optimal when the wage profile is used to provide work incentives over the lifecycle. This is a conjecture, however.

5.2.5 Empirical evidence non-competitive labor markets and OJT

The direct evidence on the effect of labor market imperfections on training is rather inconclusive (Bassanini et al., 2006). There indeed appears to be some evidence that increased opportunity costs (e.g. due to minimum wages) reduces investments in OJT. However, most empirical testing typically suffers from sample attrition biases. The reason is that more productive workers have positively selected into jobs, whereas unproductive workers would have become unemployed and vanish from the data samples being analyzed. Empirical testing of different labor market settings on cross-country data is also highly problematic. Institutions are slowly varying over time and the econometrician has to rely on cross-country differences to identify the effects. However, allowing for country-specific effects generally destroys any cross-sectional correlations found in cross-country panel analyses (see e.g. Heckman and Pages, 2003). Moreover, estimates relying on the cross-sectional dimension could be biased due to cohort effects. Ideally micro panel-data are needed to identify lifecycle impacts of various labor market settings, but this is not often done.

5.2.6 Monopsony

Both non-competitive labor markets, and deferred payments could result in the wage distributions that will not be 'compressed', but 'decompressed' over the lifecycle, since earnings at the end of the lifecycle increase and at the beginning of the lifecycle decrease. This contrasts sharply with many modern training theories that emphasize the monopsonistic nature of labor markets (see Acemoglu and Pischke, 1998; 1999). Like the literature on minimum-wages in monopsonistic labor markets (cf. Manning, 2003), this line of research essentially argues that wages are driven *below* productivity levels by firms that exert monopsonistic or oligopsonistic wage setting powers. Consequently, firms may even pay for general training, which contrasts with Becker (1964). The intuition is that productivity of workers increase faster than the wages the firm will pay, hence firms benefit from investing in general skills that increase the productivity of workers.

Since the labor market is typically inefficient due to wages that are set below labor productivity, minimum wages, unions and other wage-increasing mechanisms may in fact be second-best optimal. Monopoly-like behavior on the labor supply side is a countervailing power to monopsonistic behavior of firms so that wages can be better aligned with labor productivity, see for example Booth and Chatterji (1998) and Acemoglu and Pischke (1999, 2003).

5.2.7 Empirical relevance monopsony theories

An important empirical issue is whether wages (or, more precisely, rental rates of human capital) would indeed be driven *below* market-clearing levels, and the more so for better trained workers. All unemployment or under-utilization of human capital would then be voluntary. Moreover, a 'compressed' wage distribution would not only increase employment, but also boost investment in human capital. A priori this seems hard to believe given the apparent lack of skills of many workers who (involuntary) end up as being unemployed.

Welfare state interventions are indeed associated with compressed wage structures (Freeman and Katz, 1995; Blau and Kahn, 1996; Gottschalk and Smeeding, 1997). Non-employment is generally higher in countries with 'compressed wage structures' in comparison with countries that have more competitive labor markets. Wages are probably raised above market-clearing levels in corporatist labor markets especially at the low-end of the wage distribution and for older workers given the much larger prevalence of non-employment among these groups. At the same time, corporatist countries with stronger labor market regulations and more extensive welfare states appear to have more steeply increasing age-earnings profiles compared to the countries with more competitive labor markets (Brunello, 2000). Hence, lifecycle earnings profiles could 'de-compress', rather than 'compress' due to various labor market interventions. It is therefore important to distinguish between age-earnings profiles and cross-sectional wage-distributions. Cross-sectional wage distributions can indeed be compressed, but age-earnings profiles need not.

Monopsony-based theories have a hard time explaining unemployment, especially among the older workers. Indeed, if monopsony is the true characterization of labor market imperfections, employment rates of elderly workers would be much *higher* than employment rates of younger workers, since firms extract more monopsony-rents from the older than younger workers because they accumulated more human capital through OJT. Monopsony-based labor training theories could therefore be a red herring empirically.

5.2.8 Specific investments

Not all OJT-investment is general as already stressed by Becker (1964). Some investments in human capital are specific to the employer-worker relationship. If the labor market is perfectly competitive, the firm pays for all costs and benefits of the investment. This provides an explanation why firms seem to pay for most OJT-investments of workers (Bassanini et al. 2006). Since the firm is the residual claimant of the specific investment, one could say that the firm 'owns' all specific human capital. The worker just receives the spot wage rate in the labor market that would be obtained without any specific investments (see also Leuven, 2005). As a result, firm-specific investments in human capital cannot explain the hump-shaped age-earnings profiles. If the spot wage rate would be flat – as we assumed in the model above – then the labor earnings profile would be flat too. More generally, specific investments would typically flatten age-earnings profiles, which goes in the opposite direction of explaining the hump-shape in earnings over the lifecycle.

With specific investments in human capital, labor earnings must be higher than labor productivity at the beginning of the lifecycle and lower than labor productivity at later stages of the lifecycle if specific human capital is accumulated. The intuition runs as follows. Perfect

competition between firms ensures that profits are driven down to zero in equilibrium. Moreover assuming perfect mobility across jobs, the present value of earnings in a job with specific investments in human capital must be equal to the present value of a job without specific investments to attain equilibrium in the labor market. Thus, as long as labor productivity increases over time, the job with more investment in specific human capital pays higher wages than productivity at the beginning of the lifecycle and higher wages than productivity at the end.

Empirically, it is therefore not clear whether specific investments in human capital can go a long way in explaining age-earnings profiles and relatively low employment levels of older workers. Indeed, firms would find older workers attractive as they pay them less than their productivity. It is also practically difficult for the analyst to distinguish specific from general training. Moreover, it is not so clear whether firms really pay for most of the costs of OJT, once the general equilibrium feedbacks in the labor market have been taken into account. Indeed, the workers may pay for the investments by accepting a lower earnings-profile in a job with a lot of specific OJT-investment. Most empirical analyses abstract from these general equilibrium feedbacks.

Only if labor turnover is introduced into models of specific investments, both workers and firms typically share the costs and returns to the investment in human capital. The intuition is that the firm does not find it attractive to invest in specific investments if there is a probability that the worker will quit the firm. Then, wages will be increasing over the lifecycle. However, the presence of exogenous labor turnover must be due to some form of contract incompleteness or some form of market friction. For example, it is generally impossible for firms to claim part of the wages of workers after quitting the firm. Alternatively, there can be various sources of asymmetric information or differences in bargaining power between the employee and the firm. As a result, various types of hold-up problems emerge, which may result in inefficient levels of OJT-investment and inefficient quits (Hashimoto, 1980; Leuven and Oosterbeek, 2001; Leuven, 2005).

The empirical implications of specific OJT are similar to those of the monopsony models. Indeed, monopsony power is also driven by specificity in worker-employer relationships (Acemoglu and Pischke, 1998; 1999). Consequently, also theories on specific investments cannot explain why especially older workers would be more unemployed than younger workers.

5.2.9 Learning-by-doing

Wage profiles might not be generated by OJT, but by learning-by-doing (LBD). The basic idea is simple. As long as workers are employed, they accumulate work experience. Since older workers have accumulated more work experience, their productivity levels will be higher, and – in competitive labor markets – their wages will rise over the lifecycle. The distinguishing feature of learning-by-doing models is that there is no trade-off between current and future earnings, as in the standard human capital models. In the latter, working time and investment in OJT are rivalrous. In LBD-models they are not; current earnings raise future earnings as higher current earnings reflect more labor effort which implies that there is more learning-by-doing. See also Killingsworth (1982) and Heckman et al. (2002).

However, learning-by-doing theories resemble standard OJT-theories once a general perspective is adopted (Heckman et al. 2002). In a partial equilibrium setting, the acquisition of human capital appears as manna from heaven in LBD-theories. However, this is a problematic feature in general equilibrium. Jobs that feature a lot of LBD would have a larger present value of earnings than jobs without human capital accumulation through LBD. Equilibrium in the labor market would then require that jobs without LBD must have the same present value in earnings as jobs with LBD as long as competition drives the firms' profits to zero. Suppose that a job without LBD pays a flat rate spot wage rate, then the job with LBD must pay lower wages at the beginning of the lifecycle and higher wages at the end of the lifecycle for the present value of wages in the LBD-job to be equal to the job without LBD. Hence, the LBD-model is observationally equivalent to the standard Ben-Porath model and under some conditions they may even become identical (Killingsworth, 1982; Heckman et al. 2002). Learning-by-doing models are therefore empirically hard to distinguish from standard human capital models. Indeed, both the time invested in OJT-investments and the time accumulating work experience are hard to measure. As such, there appears no clear-cut way to empirically discriminate between the two theories.

5.3 Measurement of investment and returns

A major empirical problem in the training literature is that investment in OJT (flow) or human capital (stock) are extremely difficult to measure precisely. Both are not easily directly verifiable to the econometrician. Indeed, Heckman (2000) and Carneiro and Heckman (2003) argue that most training is informal, rather than formal. This fundamental non-verifiability of OJT-investments severely limits the applicability of commonly employed training measures, which are often based on subjective data (firms or employees) on formal investment in OJT. Generally dummy-variables are employed in regression analyses that indicate whether workers have participated in (some) training. Moreover, the intensity of training is not always known with much precision. Further, firms and employees seem to have different views on the participation/intensity of training. See also Leuven (2005) for an elaborate review.

Not only the costs (i.e. the investment in OJT), but also the returns (future) wages are difficult to measure empirically. The reason is that earnings are not equal to labor productivity even if labor markets are perfectly competitive, since time-investment in OJT drives a wedge between gross labor productivity and gross labor earnings. This is something that is often overlooked (see, for examples, Skirbekk, 2005, p16-18; Bassanini et al. 2006, p. 9). Clearly, time costs are the most important ingredient of investment in human capital (Mincer, 1958, 1962; Schultz, 1963; Becker, 1964; Trostel, 1993). Thus, worker productivity cannot be inferred from labor earnings. Hence, the returns to OJT are quite difficult to measure as a result. Heckman et al. (1998) do obtain estimates, however, by identifying skill prices per unit of human capital from the earnings of the older workers who are in their latest years of their careers. Indeed, human capital investments would approximately be zero for these workers, so that labor earnings indeed reflect productivity.

6 Remaining gaps in knowledge: main challenges

The main question is: how can we understand, both qualitatively and quantitatively, the lifecycle interactions between investing in human capital, retirement and pension saving? We started this paper by argueing that answers to these questions are highly policy relevant, but there is no framework available to understand these interactions. Therefore, we proceeded by developing one in this paper.

The framework we sketched helped us to shed light on a number of potentially important lifecycle interactions. However, the framework not only answered questions, but also raised numerous new ones. This final section attempts to sketch a research agenda for the future. This research agenda can be summarized as follows:

- Theory: developing lifecycle models of human capital investment in distorted labor markets;
- Empirics 1: employing structural econometrics to identify non-observable investment in human capital;
- Empirics 2: exploiting quasi-experimental evidence to identify institutional impacts;
- Data: using micro panel data.

The remainder of this section will explain the research agenda in more detail.

6.1 Theory

We do not yet know what is the most appropriate theory that describes human capital formation and earnings over the lifecycle. This paper started from the Ben-Porath (1967) model of general OJT-investments, which is firmly grounded in neoclassical human capital theory. This is a useful benchmark, given that the empirical evidence is completely in line with the predictions of the theory.

However, competing theories could provide alternative explanations for the patterns we see in the data. The learning-doing-theories are observationally equivalent from a general equilibrium perspective. Hence, it does not seem to matter much for practical purposes whether human capital is accumulated through training on-the-job or learning-by-doing. The theories on specific training and training in monopsonistic labor markets are clearly not compatible with standard human capital models. However, these theories have some predictions that are more difficult to reconcile with the data. Incentive theories (as developed by Lazear) for sure describe some real-world features of earnings-profiles. Nevertheless, they do not say anything about human capital accumulation. Hence, for the time being, it seems most practical to start with standard human capital models – as developed in this paper.

Market failures and institutions are likely to be very important, but little is known on their impacts. Although some work on this has been done in static or one-shot models of investment in OJT, the literature in the field shows a completely scattered picture of the impacts of different labor market settings and institutions on OJT or lifecycle earnings.

A fundamental empirical problem is that most empirical analyses are confined to working individuals only. Hence, most data samples suffer from potentially severe attrition problems, since they do not include non-working individuals that could have been priced out of the labor market. Consequently, the identification of the impact of various labor market imperfections and institutions could be seriously flawed. Moreover, the role of capital markets, saving and pension policies for human capital investments is a seriously underresearched area.

6.2 Structural estimation

Even if one accepts the most simple human capital framework to analyze human capital investments over the lifecycle, one runs into a host of methodological and data problems. Indeed, the data are likely to remain a substantial bottleneck, because training in firms is hard to verify/measure by the analyst. Also, the returns to OJT are difficult to quantify given the non-verifiability of investments (flows) and human capital levels (stocks).

Developing structural models appears to be the most promising, and we think the only route for future research. Time-investment in human capital is mostly informal and cannot, by definition, be precisely measured by researchers (Carneiro and Heckman, 2003). By estimating structural models one can identify non-observables such as time invested in OJT (see e.g. Heckman et al. 1998; Heckman et al., 2002). It seems to be unwise to continue on the path of using very soft, noisy, and often subjective data on training efforts by workers and firms. Bassanini et al. (2006) and Leuven (2005) identify major problems with this approach.

However, structural empirical models need to be firmly grounded in theory. The identification of non-observables is as good as the theoretical structure that is imposed on the data. In particular, the modeling of the market structure is key. Before any serious structural estimation can be done, it is therefore urgent to theoretically analyze labor market imperfections, capital markets and various institutional details in dynamic human capital models.

6.3 Quasi-experiments

The empirical literature produced disappointingly little evidence on the impacts of labor market institutions on investment in human capital. The difficult measurement of costs and returns of investment in human capital is, again, one of the culprits. However, also identification problems in estimating the impact of various market structures on OJT-investments are pervasive, since many of the impacts of labor market and institutional details may not be individual specific and only change slowly over time. Consequently, structural methods (to identify OJT-investment) should be combined with quasi-experimental evidence (for example, due to policy-changes, or discontinuities in policies, etc.) or instrumental variables to estimate the impact of institutions, labor and capital markets for the lifecycle patters of earnings, OJT-investments, saving and retirement.

6.4 Micro panel data

Panel data should ideally be used to identify lifecycle interactions. Estimates based on cross-sectional data could be biased, since lifecycle patterns for individuals do generally not coincide

with cross-sectional patterns. Moreover, panel data allow the econometrician to eliminate some of non-observed individual heterogeneity. Finally, panel data are suitable to estimate the impact of quasi-experiments.

Data collection should take into account that labor market frictions may result in censored samples, since some workers are priced out of labor markets. These workers need to be included for any meaningful empirical assessment of the impact of labor market distortions and labor market institutions.

We believe that gathering more aggregate cross-country evidence is not very helpful to gain more understanding of labor markets and lifecycle behavior of individuals. Indeed, empirical cross-country analyses have produced little, if any, empirical evidence, due to limited time-series variation within countries, and large sensitivity of estimation results to country-fixed effects.

7 Current state of play of European research infrastructures and networks

The main problem is that there is no 'current state of play of European research infrastructures and networks'. Various research groups operate within their own disciplines. A large group of mainly microeconomists has done extensive theoretical and empirical work on training. See the authors of Bassanini et al. (2005), and the many papers they cite. However, the theoretical focus of this line of research is mainly on stylized static or one-shot human capital investment models. The empirical work is microeconomic in nature and emphasizes instrumental variables, and quasi-experimental evidence. Only James Heckman and his co-authors have so far developed structural models of training in lifecycle settings (see for example, Heckman et al. 1998; Heckman et al., 2002).

Similarly, there are also numerous researchers working on retirement. See for prominent examples the ones participating in the project of Gruber and Wise (1999, 2002). This group of authors mainly adopts a microeconometric approach. There is hardly any theory on retirement behavior. Retirement is often seen as a corner solution in labor supply choices. Alternatively, retirement is modeled according to the Stock and Wise (1990) retirement-option model (see for an overview also De Hek and Van Erp, 2007). Both instrumental variables, quasi-experimental evidence, and structural methods are commonly used in this literature. Some authors develop structural dynamic models of retirement and estimate them (for example Rust, 1989; Van der Klaauw and Wolpin, 2005; Gustman and Steinmeier, 2005; French, 2005; Blau, 2007). Human capital formation plays no discernable role in this literature.

A number of researchers have extensively analyzed saving behavior (see for example Hall and Mishkin, 1982; Hayashi, 1985; Mariger, 1987; Zeldes, 1989; Attanasio, 1995; Browning and Lusardi, 1996; and Blundell, 1988). Especially, in the research group of Richard Blundell at UCL/IFS in London a lot of research is carried out on lifecycle behavior in consumption and labor. Human capital formation is generally ignored in these lifecycle models of consumption behavior.

To our knowledge there is not a single research group in Europe analyzing the joint impacts of labor and capital markets and institutions on the incentives for on-the-job training, pension

saving and retirement.

8 Required research infrastructures, methodological innovations, data, networks etc. and consequences for research policy

The requirements to fully understand interactions between human capital, retirement and pensions are demanding. The policy questions raised in the introduction can only be answered by an innovative combination of theory, structural econometrics, quasi-experimental evidence, and micro-panel data. Despite the high policy relevance, the complexity of all this may easily become too large to obtain important results soon. Theorists should develop better lifecycle theories of human capital investment that address the role of labor markets and their imperfections, capital markets, and various institutional details. It also requires that empirical economists should start to use more structural models to identify non-observable investment in human capital. Empirical economists should also try to develop empirical strategies to test the relevance of competing theories under different labor market conditions. Identifying the role of institutions requires quasi-experiments. Only micro-panel data appear to be useful in order to fully identify lifecycle interactions, to obtain unbiased lifecycle profiles, and to make quasi-experimental evaluations. Cross-fertilization between different sub-disciplines in labor theory and econometrics appears to be critical. In order to achieve this cooperation among different research groups is vital.

Appendix

Model in discrete time

For simulation purposes we write the continuous-time model in discrete time. The utility function is given by

$$\sum_{t=0}^{T} \frac{U(C_t)}{(1+\rho)^t} + X(T-R), \quad U', X' > 0, \quad U'', X'' < 0. \tag{21}$$

The life-time household budget constraint is:

$$\sum_{t=0}^{T} \frac{C_t}{(1+r^*)^t} = \sum_{t=0}^{R} \frac{(1-\tau_L)W(1-I_t)H_t}{(1+r^*)^t} + \sum_{t=R}^{T} \frac{(1-\tau_P)P}{(1+r^*)^t}. \tag{22}$$

And the human capital accumulation equation is:

$$H_{t+1} - H_t = BF(I_t H_t) - \delta H_t, \quad 0 \leq t \leq R. \tag{23}$$

The Lagrangian for maximizing life-time utility is given by

$$\max_{\{C_t, R_t, I_t, H_t\}} \mathcal{L} \equiv \sum_{t=0}^{T} \frac{U(C_t)}{(1+\rho)^t} + X(T-R) + \sum_{t=0}^{T} \mu_{t+1} \left[(1-\delta)H_t + BF(I_t H_t) - H_{t+1}\right] \tag{24}$$

$$+\lambda_0 \left[\sum_{t=0}^{R} \frac{(1-\tau_L)W(1-I_t)H_t}{(1+r^*)^t} + \sum_{t=R}^{T} \frac{(1-\tau_P)P}{(1+r^*)^t} - \sum_{t=0}^{T} \frac{C_t}{(1+r^*)^t} \right],$$

The first-order conditions are denoted by

$$\frac{\partial \mathcal{L}}{\partial C_t} = \frac{U'(C_t)}{(1+\rho)^t} - \lambda_t = 0, \quad 0 \leq t \leq T, \tag{25}$$

$$\frac{\partial \mathcal{L}}{\partial R} = -X'(T-R) + \lambda_R \left((1-\tau_L)W(1-I_R)H_R - (1-\tau_P)P \right) \geq 0, \tag{26}$$

$$\frac{\partial \mathcal{L}}{\partial I_t} = \mu_{t+1} BF'(.)\, H_t - \lambda_t (1-\tau_L) W H_t = 0, \quad 0 \leq t \leq R, \tag{27}$$

$$\frac{\partial \mathcal{L}}{\partial H_t} = \mu_{t+1} \left[BF'(.) I_t + 1 - \delta \right] - \mu_t + \lambda_t (1-\tau_L) W (1-I_t) = 0, \quad 0 \leq t \leq R, \tag{28}$$

where $\lambda_t \equiv \lambda_0 (1+r^*)^{-t}$. And the transversality condition is

$$\mu_{R+1} = 0. \tag{29}$$

The Euler equation consumption is

$$\frac{U'(C_{t+1})}{U'(C_t)} = \frac{1+\rho}{1+r^*}. \tag{30}$$

In the simulations we employ a CRRA felicity function, $U(C_t) = \frac{C_t^{1-1/\theta}}{1-1/\theta}$, so that

$$\frac{C_{t+1}}{C_t} = \left(\frac{1+r^*}{1+\rho} \right)^{\theta}. \tag{31}$$

The retirement decision is governed by (note $I_R = 0$)

$$\frac{X'(T-R)}{\lambda_0 (1+r^*)^{-R}} \geq (1-\tau_R)(1-\tau_L) W H_R. \tag{32}$$

If $U(C_t) = \frac{C_t^{1-1/\theta}}{1-1/\theta}$ and $X(T-R) = \gamma \frac{(T-R)^{1-1/\beta}}{1-1/\beta}$, we have

$$\frac{\gamma (T-R)^{-1/\beta}}{C_0^{-1/\theta} (1+r^*)^{-R}} \geq (1-\tau_R)(1-\tau_L) W H_R. \tag{33}$$

Investment in human capital follows from

$$m_{t+1} BF'(.) = (1+r^*)(1-\tau_L) W, \tag{34}$$

where $m_t \equiv \mu_t / \lambda_t$, and we used $\frac{m_{t+1}}{m_t} = \frac{\mu_{t+1}/\lambda_{t+1}}{\mu_t/\lambda_t}$, and $\frac{\lambda_{t+1}}{\lambda_t} = \frac{1}{1+r^*}$ from $\lambda_t = \lambda_0 (1+r^*)^{-t}$.

Rewrite the first-order condition for H_t to find a first-order difference equation in m_t:

$$\left(\frac{1-\delta}{1+r^*} \right) m_{t+1} - m_t + (1-\tau_L) W = 0. \tag{35}$$

To solve this equation, define $x \equiv \frac{1-\delta}{1+r^*}$ and $b \equiv (1-\tau_L)W$ so as to find

$$m_t = x m_{t+1} + b. \tag{36}$$

Repeated substitution yields

$$m_{t+1} = m_0 x^{-t-1} - b \sum_{v=0}^{t} x^{(v-t-1)}. \tag{37}$$

Using the transversality condition ($m_{R+1} = 0$) gives

$$m_0 = b \sum_{v=0}^{R} x^v. \tag{38}$$

Hence,

$$m_{t+1} = b \sum_{v=0}^{R-t-1} x^v. \tag{39}$$

Use $b \equiv (1-\tau_L)W$ and $x \equiv \frac{1-\delta}{1+r^*}$ to find

$$m_{t+1} = \frac{(1-\tau_L)W(1+r^*)}{r^*+\delta}\left(1 - \left(\frac{1+r^*}{1-\delta}\right)^{t-R}\right). \tag{40}$$

Conditional upon the initial level of consumption C_0 and retirement R, the Euler equation for consumption pins down the whole time-path of consumption over the lifecycle. Similarly, for given R, the time-path of the marginal value of human capital m_t is fully determined. Hence, we know the total path of investment, and the evolution of the human capital stock over the entire lifecycle. We thus end up with two non-linear equations (first-order condition for retirement and the household budget constraint) in two unknowns (C_0 and R). We numerically solve this system of equations.

Uncompensated elasticity of retirement

Linearizing the first-order condition for retirement at constant human capital gives

$$-\frac{1}{\beta}\frac{d(T-R)}{(T-R)} + \frac{1}{\theta}\frac{dC_0}{C_0} = -\frac{d\tau_L}{(1-\tau_L)}. \tag{41}$$

Rewrite the first-order condition for consumption so as to obtain

$$C_t = \left(\frac{1+r^*}{1+\rho}\right)^{t\theta} C_0. \tag{42}$$

Substitute the last result in the household budget constraint – and using the definition for τ_R – to find

$$C_0 \sum_{t=0}^{T} (1+r^*)^{t(\theta-1)} (1+\rho)^{-t\theta} = (1-\tau_L)\left(\sum_{t=0}^{R} \frac{W_t(1-I_t)H_t}{(1+r^*)^t} + \tau_R \sum_{t=R}^{T} \frac{W_R H_R}{(1+r^*)^t}\right). \tag{43}$$

At constant levels of investment in human capital I_t (and therefore H_t), we have

$$\frac{dC_0}{C_0} = -\frac{d\tau_L}{1-\tau_L}. \tag{44}$$

We therefore obtain the following uncompensated elasticity of retirement $\varepsilon_R \equiv -\frac{dR}{R}\frac{(1-\tau_L)}{d\tau_L}$ with respect to the tax rate at constant investments in human capital

$$\varepsilon_R = \frac{(T-R)}{R}\beta\left(1-\frac{1}{\theta}\right). \tag{45}$$

As a consequence, $\theta > 1$ is needed to get a positive uncompensated retirement elasticity. We require a value of $\beta = 2$ if $\theta = 1.25$ in order to obtain an uncompensated retirement elasticity of 0.2 if R is calibrated at $R = 40$ and the life-span $T = 60$.

Note that if human capital responds adversely to a lower retirement age, the interaction with human capital raises the retirement elasticity. This would not affect the qualitative nature of the effects of a tax change, i.e. the condition that $\theta > 1$ ($\theta < 1$) is still necessary to obtain a positive (negative) uncompensated elasticity of retirement. It would only make the retirement choice more elastic.

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