First publ. as: CESifo Working Paper, No. 2806, 2009

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Bas Jacobs
Dirk Schindler

CESIFO WORKING PAPER NO. 2806
CATEGORY 1: PUBLIC FINANCE
SEPTEMBER 2009

CESifo *Working Paper No. 2806*

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Abstract

This paper analyzes optimal linear taxes on labor income and savings in a standard two-period life-cycle model with endogenous leisure demands in both periods and non-insurable income risks. Households are subject to skill shocks in both periods of the life-cycle. We allow for completely general skill processes including those with persistence in skill shocks. We demonstrate that capital taxes are optimal since they reduce moral hazard in social insurance in two distinct ways: i) capital taxes reduce labor supply distortions on second-period labor supply, since second-period labor supply and saving are substitutes, ii) capital taxes reduce distortions in first-period labor supply by allowing for a lower level of labor taxes, although this effect is partially off-set because first-period labor supply and saving are complements. Capital taxes will be more attractive for social insurance if a larger part of risk is realized in the first period of the life-cycle. Our results suggest that taxing (retirement) saving is optimal to boost the retirement age and to reduce the tax-burden on working-age individuals.

JEL Code: H21, D80.

Keywords: optimal capital taxation, risk, Atkinson-Stiglitz theorem.

Bas Jacobs
Erasmus School of Economics
Erasmus University Rotterdam
PO box 1738
3000 DR Rotterdam
The Netherlands
bjacobs@ese.eur.nl

Dirk Schindler
Department of Economics
University of Konstanz
Fach D133
78457 Konstanz
Germany
dirk.schindler@uni-konstanz.de

September 23, 2009
Major parts of the paper have been written during a research stay of both authors at the Norwegian School of Economics and Business Administration in Bergen. Schindler also visited the Erasmus School of Economics and the Center of Economic Studies in Munich. The hospitality and support of all these institutions are cordially acknowledged. Bas Jacobs is grateful to the Dutch Organization for Sciences for financial support (Vidi Grant No. 452-07-013, `Skill Formation in Distorted Labor Markets'). Dirk Schindler gratefully acknowledges support by the Fritz-Thyssen-Stiftung.

"[T]he conventional argument ignores the possibility that a tax on interest income might be desirable in order to offset the distortions introduced by a tax on labour earnings." (Atkinson and Sandmo, 1980, p. 529)

1 Introduction

Should capital income be taxed or not? This is one of the oldest and most important questions in public finance. Ever since the seminal work of Pigou (1928) the desirability of taxing capital income has been widely debated. Our paper contributes to this long-standing debate by highlighting the role of non-insurable labor income risks. We show that under risk the optimal capital tax is always non-zero and this has important implications for designing pension reforms and the tax treatment of retirement savings.

Taxes on capital income are commonly seen as an ever-increasing tax on consumption in the more distant future. Ramsey-principles therefore insist that in the long-run capital income should not be taxed when infinite horizon models are analyzed (cf. Chamley, 1986; Judd, 1985, 1999). Since taxes on capital incomes are differentiated consumption taxes, these results are intimately linked to the debate on the desirability of differentiated commodity taxes. Sandmo (1974, 1976), Atkinson and Stiglitz (1976), and Deaton (1979) have demonstrated that commodity taxes should not be differentiated in finite horizon models as long as preferences over consumption goods are weakly separable from leisure under non-linear income taxation. With linear instruments the subutility function over consumption goods needs to be homothetic as well. This result is generally referred to in the literature as the Atkinson-Stiglitz-theorem.

Our paper investigates the desirability of capital income taxes when insurance markets are missing and individuals are subject to earnings risk. To that end, we develop a standard two-period life-cycle model where individuals optimally decide on consumption and leisure choices in both periods. Individuals could be hit by a non-insurable skill shock in each period of their life-cycle. Ex ante, all individuals are identical. Ex post they differ due to the realizations of these skill shocks. We allow for completely general skill-processes that could feature persistence over the life-cycle. Capital markets are assumed to be perfect. A government with full commitment designs an optimal second-best social insurance package consisting of state-independent transfers and linear, time-invariant taxes on labor and capital incomes.

We find that capital income taxes are non-zero in an optimal social insurance policy and should be positive under weak conditions that are likely to be fulfilled in practice. We find a generic role for capital income taxes even when adopting standard preferences that render capital income taxes zero in the absence of risk. Hence, we demonstrate that the Atkinson and Stiglitz (1976) theorem of zero commodity tax differentiation breaks down under risk. We show that capital income taxes could directly boost labor supply or they allow for lower levels of labor taxation, so that labor supply is indirectly stimulated while maintaining the same level of insurance. We show that capital income taxes might be used as well directly for social insurance if labor income risks are mainly concentrated in the first stage of the life-cycle.

Our paper contributes to the existing literature in a number of ways. First, Cremer and Gahvari (1995a, 1995b, 1999) have investigated the desirability of commodity tax differentiation in risky environments. Using linear policies, Cremer and Gahvari (1995a) have shown that the Atkinson-Stiglitz theorem fails in a special case of our more general model. In particular, Cremer and Gahvari (1995a) argue that commodity tax differentiation helps to offset over- or underconsumption – relative to the first-best rules – of pre-committed and post-committed goods, i.e., goods that are consumed before or after the skill shock materializes. Translated to our setting this would imply that the government would like to tax precautionary saving. However, in our view their explanation for this result needs to be revised. We demonstrate that in their setting, the capital tax does not reduce the exposure to labor market risk. Hence, the capital tax has no additional insurance gains in comparison with the labor tax, while upsetting the optimal private response to earnings risk by taxing savings in a distortionary way. Instead, we show that the capital tax boosts labor supply, and thereby indirectly reduces moral hazard in social insurance. Consequently, positive capital taxes are optimal to reduce labor market distortions, and are not employed to reduce precautionary saving.[1]

Second, Diamond and Mirrlees (1978, 1986) and papers in the 'new dynamic public finance' literature show that intertemporal wedges in consumption choices are optimal (see e.g. Golosov et al. 2003, 2006; Kocherlakota, 2005; Golosov and Tsyvinski, 2006; Albanesi and Sleet, 2006; Diamond, 2006). Labor supply optimally carries a wedge (i.e., is distorted) for insurance purposes. Moreover, there is an intertemporal wedge in consumption choices, indicating a potential role for capital income taxation or asset testing. Under particular assumptions such as independent skill shocks or time-varying non-linear policies that can be conditioned on entire earnings histories ('perfect record keeping'), the intertemporal consumption wedges can be implemented as marginal taxes on savings. By showing that capital income taxes are optimally used to boost labor supply, our paper contributes to the understanding as to why the intertemporal wedges in consumption are optimal. Indeed, the only mechanism whereby incentive compatibility constraints can be relaxed is that intertemporal consumption wedges boost labor supply. Hence, taxes on saving are optimal only if they reduce moral hazard in social insurance. In addition, by directly implementing the optimal allocations with time-invariant linear tax instruments without record keeping we also demonstrate that the basic results derived

[1] Cremer and Gahvari (1995b) show that the results carry over to non-linear instruments as well. Cremer and Gahvari (1999) extend their previous approaches by allowing for different types of commitment. Nevertheless, also in these papers the main argument is that differentiated commodity taxes mitigate socially inefficient under- and over-consumption.

in the new dynamic public finance literature are robust to (very) large deviations from the informational requirements to implement time-dependent, non-linear policies.

Third, we contribute to the existing optimal tax literature under earnings risk and we show that capital income taxes are employed in an optimal social insurance package in a wide class of standard two-period life-cycle models with risk. The model of Cremer and Gahvari (1995a) is a special case of our model where labor supply in the first period is exogenous. This setting also resembles the models of Diamond and Mirrlees (1978, 1986) where individuals can retire early. In this setting, second-period labor supply can be interpreted as the retirement decision. We will denote this the 'working-for-retirement' model. Alternatively, we also analyze a case where second-period labor supply is assumed to be exogenous, and individuals only work in the first period. This 'saving-for-retirement' model is similar to the models analyzed by Ordover and Phelps (1979) and Atkinson and Sandmo (1980). We demonstrate that capital income should optimally be taxed at positive rates in both sub-models. In particular, taxing savings helps to off-set the tax distortions on retirement in the working-for-retirement model, since a lower level of saving stimulates later retirement. In the saving-for-retirement model, subsidies on saving boost labor supply of the young workers, and thereby reduce moral hazard in social insurance. However, the higher level of labor taxes needed to finance the saving subsidies more than off-sets this positive effect on labor supply. Intuitively, both tax instruments feature social insurance gains. Hence, taxes (not subsidies) on saving are optimal so as to smooth the dead weight costs of social insurance over both the labor and capital tax bases. In our full model, we incorporate endogenous leisure demands in both periods of the life-cycle. The optimal capital tax tends to be positive for both reasons discussed in the two special cases. In contrast, capital taxes are less attractive if labor income taxes are relatively more efficient to insure income risks, since labor taxes reduce both first- and second-period earnings risk, whereas capital income taxes can only reduce first-period income risk.

Numerous other papers have elucidated the conditions under which capital income taxes are not optimally zero. If horizons are not infinite and preferences do not meet the required separability conditions, capital income might be taxed or subsidized on a net basis. In particular, when marginal rate of substitution between future and current consumption increases with labor effort, capital incomes should optimally be taxed so as to (partially) off-set the tax distortions of the income tax on labor supply. See for example Ordover and Phelps (1979), Atkinson and Sandmo (1980), Erosa and Gervais (2002), Golosov et al. (2006), and Diamond (2006). Aiyagari (1995) allows for incomplete financial markets such that individuals can be borrowing constrained. Capital income taxes redistribute resources from unconstrained towards constrained phases of the life-cycle, and thereby help to complete missing borrowing markets. Saez (2002), Boadway and Pestieau (2003), and Diamond (2006) allow for heterogeneous preferences. They show that when discount rates decrease with ability, it is optimal to tax capital income in a redistributive program even under separable preferences. In case governments cannot commit to future tax plans, optimal time-consistent capital taxes might also be (very) high, see, for example, Kydland and Prescott (1977) and Fischer (1980).

Our paper has substantial policy relevance. In the upcoming decades, many countries are confronted with the ageing of work forces, resulting in financing problems for PAYG-pensions and health care. Our results indicate that if governments aim to promote later retirement, they should not strengthen incentives to save for retirement at the same time. We show that stronger incentives for retirement saving will promote earlier retirement, not later retirement. Similarly, if governments would like to promote labor supply of working-age individuals, they should not stimulate (pension) savings either. For a given level of social insurance, the rise in the tax burden needed to finance the saving subsidies reduces labor supply of working-age individuals more than the saving subsidies can offset. Thus, the trade-off between incentives and insurance worsens as a result.

The remainder of this paper is structured as follows. Section 2 presents the baseline model. Section 3 derives the optimal tax rules for optimal labor and capital taxes. Section 4 derives the optimal tax structure in the 'saving-for-retirement' model. Section 5 derives the optimal tax structure in the 'working-for-retirement' model. Section 6 gives the solution to the complete model. Section 7 concludes. An appendix contains the technical details of the derivations.

2 Model

2.1 Households

There is a continuum of infinitely small households who live for two periods. In each period households decide upon their consumption and labor supply. Perfect capital markets allow individuals to borrow and lend at constant real interest rate r. In addition, labor markets are frictionless and the wage per efficiency unit of labor equals one.[2] Insurance markets to insure idiosyncratic labor income risks are missing, which can be due to moral hazard, adverse selection, and contract incompleteness (see, e.g., Sinn, 1996). By the law of large numbers idiosyncratic individual risk washes out in aggregate and there is no aggregate (systematic) risk.

Households are identical ex ante, but not ex post. In each period $i = 1, 2$, their productivity per hour worked or 'skill' θ_i is stochastic. The joint set of possible realizations is denoted by $\Theta \equiv \left[\underline{\theta}_1, \overline{\theta}_1\right] \times \left[\underline{\theta}_2, \overline{\theta}_2\right]$, where $\underline{\theta}_1 > 0$ and $\underline{\theta}_2 > 0$. $\theta \equiv \{\theta_1, \theta_2\} \in \Theta$ denotes a skill history of θ_1 and θ_2. We will denote by $\Theta_i \equiv \left[\underline{\theta}_i, \overline{\theta}_i\right]$ the set of realizations of θ_i for

[2] Constant real interest and wage rates would be obtained in a small open economy with perfect capital mobility and perfect substitution of different labor types in production.

$i = 1, 2$. $p(\theta)$ is the probability distribution function, which attaches a probability $p(\theta)$ to skill history θ. The conditional probability that θ_2 is realized given θ_1 is denoted by $p(\theta_2|\theta_1)$. The (life-time) expectation $\mathrm{E}[.]$ over variable $x(\theta)$ as of period one is defined as $\mathrm{E}[x(\theta)] \equiv \sum_{\Theta} x(\theta) p(\theta)$, whereas the conditional expectation of a variable as of period two, given a particular realization of the skill shock θ_1 in period one, is denoted by $\mathrm{E}[x(\theta_2)|\theta_1] \equiv \sum_{\Theta_2} x(\theta_2) p(\theta_2|\theta_1)$. We allow for fully general stochastic processes for the evolution of skills, hence there could be persistence in skill shocks over time if their correlation is positive. For notational simplicity we harmlessly normalize the expectation of the first skill shock to one: $\mathrm{E}[\theta_1] \equiv 1$.

c_i denotes consumption in period $i = 1, 2$. Similarly, l_i is labor supply in period i. In period one, households choose labor supply and consumption before the shock realizes, hence c_1 and l_1 are 'committed' goods (Cremer and Gahvari, 1995a, 1995b). When entering the second period, households carry forward a stochastic level of assets $a(\theta_1)$ and first determine how much labor $l_2(\theta_1)$ to supply. Hence, second-period labor supply only depends on shock θ_1 and not on θ_2. Second-period consumption $c_2(\theta_1, \theta_2)$ is determined residually.[3]

We follow common practice in the optimal tax literature under risk by assuming that expected utility U is an additively separable function over consumption and labor supply in both periods (see also Cremer and Gahvari, 1995a, 1995b; Golosov et al., 2003, 2006; Diamond, 2006):

$$\begin{aligned} U &\equiv u_1(c_1) - v_1(l_1) + \beta \mathrm{E}\left[u_2(c_2(\theta_1, \theta_2)) - v_2(l_2(\theta_1))\right], \qquad (1) \\ & \quad u_i', v_i' > 0, \quad u_i'', -v_i'' < 0, \quad 0 < \beta < 1, \quad i = 1, 2, \end{aligned}$$

where sub-utilities u_i and v_i satisfy the Inada-conditions. β is the discount factor, which captures the time-preference of the household. We assume decreasing absolute risk aversion in consumption, which necessarily implies $u_i''' > 0$.

The government employs linear tax instruments. The informational requirements for these instruments are that the government only observes aggregate tax bases. In particular, the government levies a linear tax on labor earnings in both periods at rate t. In addition, the household receives non-state dependent transfers T in the first period. We do not explicitly allow for a second-period income transfer. This instrument is redundant, since individuals can freely allocate the first-period transfer over the life-cycle by having perfect access to capital markets. Finally, a linear tax at rate τ is levied on interest income from savings.[4]

[3] We have also derived the model where labor supply in each period is chosen after the shock has realized. The optimal tax expressions remain the same. However, they contain the expected elasticity of first-period labor income rather than the deterministic elasticity. The expected elasticity of second-period labor also depends on the second skill shock. See also Anderberg and Andersson (2003).

[4] Cremer and Gahvari (1995a) study a similar setting with only second-period labor supply using dif-

We restrict the analysis to linear policies. Linear tax systems are always incentive compatible, since households with favorable skill shocks cannot gain by mimicking households with unfavorable shocks, because the tax system does not discriminate tax rates by levels of earnings or levels of assets. Therefore, the optimal second-best allocation can directly be implemented as a decentralized competitive market outcome with taxes. Non-linear policies have been extensively analyzed in, for example, Golosov et al. (2003), Kocherlakota (2005), Golosov et al. (2006), and Diamond (2006). Non-linear instruments are much more demanding in terms of information as they require verifiability of labor incomes and savings at the individual level, and also need to be differentiated over time. Optimal non-linear policies also need to respect incentive compatibility constraints. Generally, in dynamic optimal tax models with risk optimal second-best allocations cannot be implemented with non-linear instruments unless specific assumptions are made on the dynamics of the skill process or the set of available government instruments (e.g., record keeping), see for example Golosov et al. (2003), Kocherlakota (2005), Albanesi and Sleet (2006), and Golosov and Tsyvinski (2006). We do neither impose any restrictions on the skill process nor require perfect record keeping.

In the first period, the household works and earns $\theta_1 l_1$ in gross labor earnings. The first-period budget constraint states that total consumption equals net labor income minus saving $a(\theta_1)$:

$$c_1 = (1-t)\theta_1 l_1 + T - a(\theta_1), \quad \forall \theta_1 \in \Theta_1. \tag{2}$$

In the second-period, the household earns net labor income $(1-t)\theta_2 l_2(\theta_1)$ and interest income $ra(\theta_1)$ on assets carried forward from period one. Interest income is taxed at flat rate τ. Hence, the second-period budget reads as

$$c_2(\theta_2,\theta_1) = (1-t)\theta_2 l_2(\theta_1) + (1+(1-\tau)r)\, a(\theta_1), \quad \forall \{\theta_1,\theta_2\} \in \Theta. \tag{3}$$

In the remainder, we will employ $R \equiv 1 + (1-\tau)r$ to denote the net interest factor.

The household maximizes life-time utility by choosing the optimal levels of consumption c_i and labor supply l_i. We solve this problem backwards. Individuals enter the second period with a stochastic level of assets $a(\theta_1)$. Given this level of assets, and before the second shock θ_2 materializes, the individual solves the subprogram:

$$\max_{\{l_2(\theta_1)\}} \mathrm{E}\left[u_2((1-t)\theta_2 l_2(\theta_1) + Ra(\theta_1)) - v_2(l_2)\,|\theta_1\right], \quad \forall \theta_1 \in \Theta_1, \tag{4}$$

ferentiated commodity taxes. In the absence of non-labor income, such as bequests, uniform commodity taxes are equivalent to a proportional tax on labor income, without taxes on capital income. Non-uniform commodity taxes are equivalent to a labor income tax supplemented with taxes or subsidies on capital income.

which yields the following first-order condition for second-period labor supply:

$$(1-t)\mathrm{E}\left[u_2'(\theta_2)\,\theta_2|\theta_1\right] = v_2'(l_2(\theta_1)), \quad \forall \theta_1 \in \Theta_1. \tag{5}$$

Consequently, we can write for the conditional expectation of second-period indirect utility:

$$\mathrm{E}\left[W(\theta_2, a(\theta_1))\,|\theta_1\right] \equiv \mathrm{E}\left[u_2(\hat{c}_2) - v_2\left(\hat{l}_2\right)|\theta_1\right], \quad \forall \theta_1 \in \Theta_1, \tag{6}$$

where hats are used to denote the optimal values of c_2 and l_2. Taking expectations as of period one on both sides yields expected indirect utility in period two as a function of saving and the skill shocks:

$$\begin{aligned} \mathrm{E}\left[W(a(\theta_1), \theta_1, \theta_2)\right] &\equiv \mathrm{E}\left[u_2(\hat{c}_2(\theta_1,\theta_2)) - v_2\left(\hat{l}_2(\theta_1)\right)\right] \\ &= \mathrm{E}\left[u_2\left((1-t)\theta_2\hat{l}_2(\theta_1) + Ra(\theta_1)\right) - v_2\left(\hat{l}_2(\theta_1)\right)\right]. \end{aligned} \tag{7}$$

Straightforward differentiation yields $\frac{\partial \mathrm{E}[W(a(\theta_1),\theta_1,\theta_2)]}{\partial a(\theta_1)} = R\mathrm{E}\left[u_2'(c_2(\theta_1,\theta_2))\right].$

In the first stage, individuals choose c_1 and l_1 before the shock θ_1 realizes, conditional upon optimal choices in the second period. Hence, the individual solves the following subprogram:

$$\begin{aligned} \max_{\{c_1,l_1\}} U &= u_1(c_1) - v_1(l_1) + \beta\mathrm{E}\left[W(a(\theta_1), \theta_1, \theta_2)\right] \\ &= u_1(c_1) - v_1(l_1) + \beta\mathrm{E}\left[W((1-t)\theta_1 l_1 + T - c_1, \theta_1, \theta_2)\right], \end{aligned} \tag{8}$$

where we substituted saving from the individual budget constraint in equation (2) in the second line. The first-period labor supply equation is governed by

$$v_1'(l_1) = (1-t)\beta R\mathrm{E}\left[u_2'(c_2(\theta_1,\theta_2))\,\theta_1\right] \tag{9}$$

The first-order conditions also imply the standard stochastic Euler-equation for consumption:

$$u_1'(c_1) = \beta R\mathrm{E}\left[u_2'(c_2(\theta_1,\theta_2))\right] \tag{10}$$

A higher real return on saving R or a higher discount factor β make individuals more willing to save by substituting current for future consumption.[5]

We introduce the risk premia of first- and second-period labor supply as the normalized covariance between the marginal utility of second-period consumption and the skill shocks θ_1 and θ_2:

$$\pi_1 \equiv -\frac{cov\left[u_2'(c_2(\theta_1,\theta_2)), \theta_1\right]}{\mathrm{E}\left[u_2'(c_2(\theta_1,\theta_2))\right]\mathrm{E}\left[\theta_1\right]} \geq 0, \tag{11}$$

[5]Second-order conditions are always fulfilled due to the assumptions on preferences.

$$\pi_2 \equiv -\frac{cov\left[u_2'\left(c_2\left(\theta_1,\theta_2\right)\right),\theta_2\right]}{\mathrm{E}\left[u_2'\left(c_2\left(\theta_1,\theta_2\right)\right)\right]\mathrm{E}\left[\theta_2\right]} \geq 0. \tag{12}$$

π_i denotes the marginal welfare loss due to skill risk in period i expressed in monetary units. Because marginal utility of income is declining with income, the risk premia are non-negative in both periods. Given that risk affects labor earnings in a multiplicative way, larger labor supply raises the risk-exposure of households to labor market shocks.

Using these definitions, we can derive that the labor supply equations in both periods can be written as:

$$\frac{v_1'\left(l_1\right)}{u_1'\left(c_1\right)} = \left(1-\pi_1\right)\left(1-t\right), \tag{13}$$

$$\frac{\mathrm{E}\left[v_2'\left(l_2\left(\theta_1\right)\right)\right]}{\mathrm{E}\left[u_2'\left(c_2\left(\theta_1,\theta_2\right)\right)\right]} = \left(1-\pi_2\right)\left(1-t\right)\mathrm{E}\left[\theta_2\right]. \tag{14}$$

Hence, individuals get stronger incentives to supply more labor if the tax rate is lower or if labor income is less risky (lower π_i). Larger labor market risk, as indicated by a larger π_i, acts as an implicit tax on labor supply, since risk averse individuals reduce their labor effort if the latter raises their exposure to skill shocks.

Indirect expected utility of the household can be written as a function V over the policy variables (T, t, R):

$$V\left(T,t,R\right) \equiv u_1(\hat{c}_1) - v_1\left(\hat{l}_1\right) + \beta\mathrm{E}\left[u_2(\hat{c}_2) - v_2\left(\hat{l}_2\right)\right]. \tag{15}$$

where the hats indicate the optimized values for consumption and labor, which follow from solving the three first-order conditions (5), (9), and (10), and the household budget constraints (2) and (3) for c_1, c_2, l_1, l_2 and a. Note that we have suppressed the skill shocks for notational simplicity. We will continue to do so in the remainder of the paper.

The derivatives of indirect utility with respect to the policy instruments follow from applying Roy's lemma:

$$\frac{\partial V}{\partial T} = \eta, \tag{16}$$

$$\frac{\partial V}{\partial t} = -\eta\left((1-\xi_1)l_1 + \frac{(1-\xi_2)\mathrm{E}\left[\theta_2 l_2\right]}{R}\right), \tag{17}$$

$$\frac{\partial V}{\partial R} = \eta\frac{((1-\xi_1)\left(1-t\right)l_1 - c_1 + T)}{R}, \tag{18}$$

where $\eta \equiv u_1'\left(c_1\right) = \beta R\mathrm{E}\left[u_2'\right]$ is the marginal utility of private income, and ξ_1 and ξ_2 are the insurance characteristics of first and second-period labor incomes

$$\xi_1 \equiv -\frac{cov\left[u_2', \theta_1 l_1\right]}{\mathrm{E}\left[u_2'\right]\mathrm{E}\left[\theta_1 l_1\right]} \geq 0, \tag{19}$$

$$\xi_2 \equiv -\frac{cov\left[u_2', \theta_2 l_2\right]}{\mathrm{E}\left[u_2'\right]\mathrm{E}\left[\theta_2 l_2\right]} \geq 0. \tag{20}$$

The insurance characteristic ξ_i gives the marginal welfare loss of income risk in period i expressed in monetary units. In particular, $(1-\xi_i)\mathrm{E}\left[\theta_i l_i\right]$ is the certainty equivalent of risky labor income $\theta_i l_i$.

To solve for the optimal tax structure below, we employ the risk-adjusted Slutsky equations. To that end, we define the expenditure function $X\left(t,R,V\right)$ as the minimum level of non-labor income T required to attain expected indirect utility V. $X\left(.\right)$ can be obtained from setting $X\left(t,R,V\right) \equiv T$ for the optimal level of indirect utility V as given in equation (15). The compensated demand functions are then defined as

$$l_i^c\left(t,R,V\right) \equiv l_i\left(t,R,X\left(t,R,V\right)\right), \tag{21}$$

$$c_i^c\left(t,R,V\right) \equiv c_i\left(t,R,X\left(t,R,V\right)\right), \tag{22}$$

where the superscript c denotes a compensated change. By totally differentiating the compensated demand functions for given V, and using Shephard's lemma we obtain the following risk-adjusted Slutsky equations for l_1, l_2, and c_1 with respect to t and R:

$$\frac{\partial l_1}{\partial t} = \frac{\partial l_1^c}{\partial t} - \left((1-\xi_1)l_1 + \frac{(1-\xi_2)\mathrm{E}\left[\theta_2 l_2\right]}{R}\right)\frac{\partial l_1}{\partial T}, \tag{23}$$

$$\frac{\partial l_2}{\partial t} = \frac{\partial l_2^c}{\partial t} - \left((1-\xi_1)l_1 + \frac{(1-\xi_2)\mathrm{E}\left[\theta_2 l_2\right]}{R}\right)\frac{\partial l_2}{\partial T}, \tag{24}$$

$$\frac{\partial c_1}{\partial t} = \frac{\partial c_1^c}{\partial t} - \left((1-\xi_1)l_1 + \frac{(1-\xi_2)\mathrm{E}\left[\theta_2 l_2\right]}{R}\right)\frac{\partial c_1}{\partial T}, \tag{25}$$

$$\frac{\partial l_1}{\partial R} = \frac{\partial l_1^c}{\partial R} + \frac{\left((1-\xi_1)(1-t)l_1 - c_1 + T\right)}{R}\frac{\partial l_1}{\partial T}, \tag{26}$$

$$\frac{\partial l_2}{\partial R} = \frac{\partial l_2^c}{\partial R} + \frac{\left((1-\xi_1)(1-t)l_1 - c_1 + T\right)}{R}\frac{\partial l_2}{\partial T}, \tag{27}$$

$$\frac{\partial c_1}{\partial t} = \frac{\partial c_1^c}{\partial R} + \frac{\left((1-\xi_1)(1-t)l_1 - c_1 + T\right)}{R}\frac{\partial c_1}{\partial T}. \tag{28}$$

2.2 Government

We assume a benevolent government, which has full commitment. We abstract from a government revenue requirement without loss of generality. The government optimally provides social insurance by choosing policy instruments T, t, and R, such that expected indirect utility $V\left(T,t,R\right)$ of the household is maximized.

By the law of large numbers individual idiosyncratic risks cancel in the aggregate and we find that the government budget constraint is given by

$$(1+r)tl_1 + t\mathrm{E}\left[\theta_2 l_2\right] + (1+r-R)\left[(1-t)l_1 - c_1 + T\right] = (1+r)T. \tag{29}$$

All labor incomes are deterministic at the aggregate level. However, this does not imply that the expectations operator on second-period labor income vanishes. The reason is that skill shocks θ_i may not be independent over time. If there is a correlation between both skill shocks, second-period income will depend on the realization of the first-period shock θ_1 and the second-period shock θ_2. As a result we have $\mathrm{E}\left[\theta_2 l_2\left(\theta_1\right)\right] \neq \mathrm{E}\left[\theta_2\right]\mathrm{E}\left[l_2\left(\theta_1\right)\right]$. Only if skill shocks are independent, i.e., if $cov\left[\theta_1,\theta_2\right] = 0$, we obtain $\mathrm{E}\left[\theta_2 l_2\left(\theta_1\right)\right] = \mathrm{E}\left[\theta_2\right]\mathrm{E}\left[l_2\left(\theta_1\right)\right]$.

3 Optimal taxation

The Lagrangian for maximizing social welfare is given by

$$\begin{aligned} \max_{\{T,t,R\}} \mathcal{L} \;\equiv\;& V\left(T,t,R\right) + \lambda\left[tl_1(1+r) + t\mathrm{E}\left[\theta_2 l_2\right]\right] \\ +\;& \lambda\left[(1+r-R)\left((1-t)l_1 - c_1 + T\right) - (1+r)T\right], \end{aligned} \tag{30}$$

where λ is the deterministic shadow value of public resources.

The first-order conditions for an optimum are[6]

$$\frac{\partial\mathcal{L}}{\partial T} = \beta R\mathrm{E}\left[u_2'\right] - \lambda R + \lambda\left(tR+\tau r\right)\frac{\partial l_1}{\partial T} + \lambda t\mathrm{E}\left[\theta_2\frac{\partial l_2}{\partial T}\right] - \lambda\tau r\frac{\partial c_1}{\partial T} = 0, \tag{31}$$

$$\begin{aligned} \frac{\partial\mathcal{L}}{\partial t} =\;& -\beta\mathrm{E}\left[u_2'\right]\left((1-\xi_1)Rl_1 + (1-\xi_2)\mathrm{E}\left[\theta_2 l_2\right]\right) + \lambda\left(Rl_1 + \mathrm{E}\left[\theta_2 l_2\right]\right) \\ +\;& \lambda\left(tR+\tau r\right)\frac{\partial l_1}{\partial t} + \lambda t\mathrm{E}\left[\theta_2\frac{\partial l_2}{\partial t}\right] - \lambda\tau r\frac{\partial c_1}{\partial t} = 0, \end{aligned} \tag{32}$$

$$\begin{aligned} \frac{\partial\mathcal{L}}{\partial R} =\;& \beta\mathrm{E}\left[u_2'\right](1-\xi_1)(1-t)l_1 - c_1 + T) - \lambda\left((1-t)l_1 - c_1 + T\right) \\ +\;& \lambda\left(tR+\tau r\right)\frac{\partial l_1}{\partial R} + \lambda t\mathrm{E}\left[\theta_2\frac{\partial l_2}{\partial R}\right] - \lambda\tau r\frac{\partial c_1}{\partial R} = 0. \end{aligned} \tag{33}$$

From the first-order condition for the lump–sum transfer in equation (31) follows that the expected social value of transferring one euro to the household (b) should be equal to its resource cost (unity):

$$b \equiv \frac{\beta\mathrm{E}\left[u_2'\right]}{\lambda} + \frac{(tR+\tau r)}{R}\frac{\partial l_1}{\partial T} + \frac{t}{R}\mathrm{E}\left[\theta_2\frac{\partial l_2}{\partial T}\right] - \frac{\tau r}{R}\frac{\partial c_1}{\partial T} = 1. \tag{34}$$

[6] We assume that these necessary first-order conditions are also sufficient to describe the optimum allocation, i.e., the second-order conditions for the government program are fulfilled.

The first-order condition for the labor tax rate in (32) can be rewritten by substituting the risk-adjusted Slutsky equations for $\frac{\partial l_1}{\partial t}$, $\frac{\partial l_2}{\partial t}$, and $\frac{\partial c_1}{\partial t}$ in (23), (24) and (25), using the definition for b in (34), and rearranging to find

$$\omega\xi_1 + (1-\omega)\xi_2 + \frac{t}{1-t}\left(\omega\varepsilon_{l_1t} + (1-\omega)\varepsilon_{l_2t}\right) + \frac{\tau r/R}{1-t}\left(\omega\varepsilon_{l_1t} - \gamma\varepsilon_{c_1t}\right) = 0, \qquad (35)$$

where $\varepsilon_{l_1t} \equiv \frac{\partial l_1^c}{\partial t}\frac{1-t}{l_1}$, $\varepsilon_{l_2t} \equiv \mathrm{E}\left[\theta_2\frac{\partial l_2^c}{\partial t}\right]\frac{1-t}{\mathrm{E}[\theta_2 l_2]}$, and $\varepsilon_{c_1t} \equiv \frac{\partial c_1^c}{\partial t}\frac{1-t}{c_1}$ designate the compensated labor tax elasticities of first-period labor income, expected second-period labor income, and first-period consumption, respectively. $\omega \equiv \frac{Rl_1}{Rl_1+\mathrm{E}[\theta_2 l_2]}$ is the share of first-period labor income in expected total labor income. $\gamma \equiv \frac{Rc_1}{Rl_1+\mathrm{E}[\theta_2 l_2]}$ is the share of first-period consumption in expected total labor income.

Similarly, we can simplify the first-order condition for the capital tax in (33) by substituting the risk-adjusted Slutsky equations for $\frac{\partial l_1}{\partial R}$, $\frac{\partial l_2}{\partial R}$, and $\frac{\partial c_1}{\partial R}$ (see equations (26) to (28)), using the definition for b in (34), and rearranging to find

$$-\omega\xi_1 + \frac{t}{1-t}\left(\omega\varepsilon_{l_1R} + (1-\omega)\varepsilon_{l_2R}\right) + \frac{\tau r/R}{1-t}\left(\omega\varepsilon_{l_1R} - \gamma\varepsilon_{c_1R}\right) = 0, \qquad (36)$$

where $\varepsilon_{l_1R} \equiv \frac{\partial l_1^c}{\partial R}\frac{R}{l_1}$, $\varepsilon_{l_2R} \equiv \mathrm{E}\left[\theta_2\frac{\partial l_2^c}{\partial R}\right]\frac{R}{\mathrm{E}[\theta_2 l_2]}$, $\varepsilon_{c_1R} \equiv \frac{\partial c_1^c}{\partial R}\frac{R}{c_1}$ denote the compensated elasticities of first-period labor income, expected second-period labor income, and first-period consumption with respect to the interest factor, respectively.

In the appendix we formally derive all the behavioral elasticities, which we have signed under three parameter restrictions, see also Table 1. Our parameter restrictions ensure that the elasticities qualitatively have the same signs as the comparative statics results of the model in the absence of income risk.

Table 1: Summary of elasticities

Elasticities	
$\varepsilon_{c_1t} \equiv -\frac{\epsilon}{\Delta} < 0$	$\varepsilon_{c_1R} \equiv \frac{\delta}{\Delta} < 0$
$\varepsilon_{c_2t} \equiv -\frac{\rho_1}{\rho_2}\frac{\epsilon}{\Delta} < 0$	$\varepsilon_{c_2R} \equiv \frac{1}{\rho_2} + \frac{\rho_1}{\rho_2}\frac{\delta}{\Delta} > 0$
$\varepsilon_{l_1t} \equiv -\varepsilon_1\left[1 - \Sigma_1\frac{\rho_1\epsilon}{\Delta}\right] < 0$	$\varepsilon_{l_1R} \equiv -\varepsilon_1\Sigma_1\left[1 + \frac{\rho_1\delta}{\Delta} - \frac{1}{\Sigma_1}\right] > 0$
$\varepsilon_{l_2t} \equiv -\varepsilon_2\left[1 - \Sigma_2\frac{\rho_1\epsilon}{\Delta}\right] < 0$	$\varepsilon_{l_2R} \equiv -\varepsilon_2\Sigma_2\left[1 + \frac{\rho_1\delta}{\Delta}\right] < 0$

Definitions
$\rho_i \equiv -\frac{\mathrm{E}[u_i''(c_i)]\mathrm{E}[c_i]}{\mathrm{E}[u_i'(c_i)]} > 0$: global relative risk aversion in consumption in period i
$\varepsilon_i \equiv \left[\frac{\mathrm{E}[v_i''(l_i)]\mathrm{E}[\theta_i l_i]}{\mathrm{E}[v_i'(l_i)]\mathrm{E}[\theta_i]}\right]^{-1} > 0$: compensated labor supply elasticity in period i
$\pi_i' \equiv -\frac{cov\left[u_2'',\theta_i\right]}{\mathrm{E}[u_2'']\mathrm{E}[\theta_i]} > 0$: 'prudence-based' risk premium in period i
$\Sigma_i \equiv \frac{1-\pi_i'}{1-\pi_i} \geq 0$: 'elasticity of residual risk aversion' in period i
$\Delta \equiv \frac{\gamma+(1-\gamma)\frac{\rho_1}{\rho_2}}{(1-t)} + (1-\pi_1)\omega\Sigma_1\varepsilon_1\rho_1 + (1-\pi_2)(1-\omega)\Sigma_2\varepsilon_2\rho_1 > 0$
$\epsilon \equiv (1-\pi_1)\omega\varepsilon_1 + (1-\pi_2)(1-\omega)\varepsilon_2 > 0$
$\delta \equiv -\frac{(1-\gamma)/\rho_2}{(1-t)} + (1-\pi_1)\omega\varepsilon_1(1-\Sigma_1) - (1-\pi_2)(1-\omega)\varepsilon_2\Sigma_2$

Parameter restrictions
i) $\delta < 0$, ii) $\Sigma_1 \approx \Sigma_2$, iii) $\pi_1' > \pi_1 \Leftrightarrow \Sigma_1 < 1$

First, $\varepsilon_{c_2R} > 0$ holds independently of any assumption on parameters. Hence, a larger net return on saving boosts second period consumption. Moreover, $\varepsilon_{c_1R} < 0$, since we assume $\delta < 0$ so that the standard substitution effect in saving dominates the insurance effect of taxes on saving. The insurance effect stems from the fact that taxes on saving help to reduce the exposure to first-period labor market shocks by reducing the variance in saving.

Second, $\varepsilon_{lt_1} < 0$ and $\varepsilon_{lt_2} < 0$. Under wage risk, the elasticities of labor supply with respect to the labor tax are generally ambiguous. By reducing the variance in earnings, a higher tax reduces the risk-exposure of individuals to adverse labor market shocks so that labor supply is ceteris paribus stimulated (see also Menezes and Wang, 2005). The change in exposure to labor market risk is captured by the 'elasticity of residual risk aversion' $\Sigma_i \equiv \frac{1-\pi_i'}{1-\pi_i}$, $\pi_i' \equiv -\frac{cov\left[u_i'',\theta_i\right]}{\mathrm{E}[u_i'']\mathrm{E}[\theta_i]}$. This elasticity measures the percentage change in the certainty equivalent of wages with respect to a one percent change in expected wages in period i.[7] However, the standard, negative substitution effect of higher taxes on labor supply pulls in the opposite direction. We assume that $\Sigma_1 \approx \Sigma_2$ so that the substitution effects in labor supply dominate the insurance effects.

Third, $\varepsilon_{c_1t} < 0$ and $\varepsilon_{c_2t} < 0$. These are unambiguous. The intuition is that a higher labor tax lowers the price of leisure and induces substitution away from consumption towards leisure.

[7] Σ_i can be compared to the 'coefficient of residual income progression', which is the elasticity of after-tax income with respect to before-tax income, see, e.g., Musgrave and Musgrave (1976).

Fourth, $\varepsilon_{l_1 R} > 0$ and $\varepsilon_{l_2 R} < 0$. A higher financial return R induces individuals to have relatively more consumption and leisure in the second-period and less consumption and leisure in the first period. Due to intertemporal substitution in leisure, labor supply in the first period increases and labor supply in the second period decreases. In addition, there are wealth effects on labor supply in both periods due to intertemporal substitution effects in consumption. Intuitively, a lower (higher) first-period (second-period) level of consumption raises (lowers) marginal utility of consumption in the first (second) period. Consequently, in the first period the marginal willingness to pay for leisure, i.e., the marginal rate of substitution between leisure and consumption, decreases and labor supply expands. Similarly, in the second period the marginal willingness to pay for leisure increases, so that labor supply diminishes. Thus, intertemporal substitution effects in both leisure and consumption increase first-period labor supply and decrease second-period labor supply. Moreover, in case of $\varepsilon_{l_1 R}$, the interest rate also has a direct, positive effect on the effective first-period wage rate by increasing its net present value in terms of second period consumption, which is the numéraire commodity. Whilst $\varepsilon_{l_2 R} < 0$ can be signed independently of any assumption on parameters, $\varepsilon_{l_1 R}$ can turn ambiguous under risk. If $\delta < 0$, a sufficient condition for $\varepsilon_{l_1 R} > 0$ is that the 'elasticity of residual risk aversion' in the first period should be smaller than one, i.e., $\Sigma_1 \equiv \frac{1-\pi_1'}{1-\pi_1} < 1$, which is equivalent to assuming $\pi_1' > \pi_1$. This restriction is harmless when the bivariate distribution of skill shocks is normal and should also hold more generally under mild conditions (see appendix). The imposed parameter restrictions are summarized in the last row of Table 1.

To gain intuition for the optimal tax structure we will first discuss two special cases before turning to the interpretation of the complete model. In the first case we assume that first-period labor supply is exogenous and there is no first-period labor income risk. We label this the working-for-retirement model, as we could interpret second-period labor supply as the retirement decision. This structure of the model corresponds to the setting analyzed in Cremer and Gahvari (1995a, 1995b) and is similar to Diamond and Mirrlees (1978, 1986). In the second case, we assume that second-period labor supply is exogenous and there is no second-period income risk. This model is denoted as the saving-for-retirement model. This structure corresponds to the deterministic analyses in Ordover and Phelps (1979) and Atkinson and Sandmo (1980).

4 Working-for-retirement: exogenous first-period leisure

In case first-period labor supply is exogenous and not risky we have: $\varepsilon_{l_1 t} = \varepsilon_{l_1 R} = \xi_1 = 0$. Labor supply can in this case also be interpreted as the retirement decision. Hence, we find from equations (35) and (36) the following first-order conditions for the optimal labor and capital income tax

$$(1-\omega)\xi_2 = -\left(\frac{t}{1-t}\right)(1-\omega)\varepsilon_{l_2 t} + \left(\frac{\tau r/R}{1-t}\right)\gamma\varepsilon_{c_1 t}, \tag{37}$$

$$0 = -\left(\frac{t}{1-t}\right)(1-\omega)\varepsilon_{l_2 R} + \left(\frac{\tau r/R}{1-t}\right)\gamma\varepsilon_{c_1 R}. \tag{38}$$

Expression (37) demonstrates that the labor tax is set in such a way that the marginal benefits in terms of larger social insurance $(1-\omega)\,\xi_2$ are equated to the net marginal dead weight costs of doing so. The net costs consist of two effects. First, a higher labor tax distorts labor supply more heavily as indicated by $-\frac{t}{1-t}\,(1-\omega)\,\varepsilon_{l_2 t} > 0$. Second, provided that capital income is taxed and households thus tend to consume too much in the first period, a higher labor tax reduces these intertemporal distortions in consumption, as can be seen from $\frac{\tau r/R}{(1-t)}\gamma\varepsilon_{c_1 t} < 0$.

The intuition for (38) is simpler. Taxes on savings are used for efficiency reasons only, since the capital tax base is deterministic. Therefore, capital taxes do not reduce the variance in risky labor earnings and the insurance characteristic ξ_2 does not play a role. Thus, taxing savings does not yield insurance benefits. The only role of the tax on saving is to mitigate the distortions on labor supply. The first term on the right-hand side gives the benefits of smaller labor supply distortions $(-\frac{t}{1-t}\,(1-\omega)\,\varepsilon_{l_2 R} > 0)$. A larger capital tax boosts second-period labor supply, since a capital tax generates a wealth effect on second-period labor supply due to intertemporal substitution effects in consumption. Note that there is no direct intertemporal substitution in leisure demand with leisure being chosen in one period only. The second term represents the costs of a saving tax in terms of a distorted pattern of consumption over the life-cycle $(\frac{\tau r/R}{1-t}\gamma\varepsilon_{c_1 R} < 0)$.

From the last equation follows the optimal dual tax structure (hats denote the optimized values):

$$\frac{\hat{\tau} r}{\hat{R}} = \frac{(1-\omega)}{\gamma}\frac{\varepsilon_{l_2 R}}{\varepsilon_{c_1 R}}\hat{t} > 0. \tag{39}$$

Equation (39) demonstrates that a dual income tax with both positive taxes on capital income and labor income is optimal as long as the labor tax is used for insurance $(t > 0)$. Below we will show that this is indeed the case. By boosting labor supply the capital tax alleviates the labor tax distortions associated with insuring labor income risks. Savings and second-period labor supply are substitutes. Therefore, taxing savings helps to reduce moral hazard in labor supply. The stronger the complementarity between first-period consumption and second-period labor supply, the larger is $\varepsilon_{l_2 R}$, and the higher should be the capital tax. If the distortions in saving are larger, $\varepsilon_{c_1 R}$ increases, and optimal capital income taxes should be set at lower levels. If more consumption is allocated towards the second-period of the life-cycle, γ is smaller and capital taxes are less distortionary. Hence, optimal capital taxes can be higher. Similarly, if relatively more labor income is earned in the second period, $(1-\omega)$ is larger and the larger are the efficiency gains of taxes on capital income. Note that optimal capital taxes would only be zero when savings and labor supply would not be substitutes ($\varepsilon_{l_2R}=0$), capital income taxes would be infinitely distortionary ($\varepsilon_{c_1R}=\infty$), or second-period labor income would be zero ($\omega=1$). None of these conditions would be fulfilled with standard preferences.

By using the optimal dual income tax we can obtain the following expression for the optimal labor tax at the optimal capital tax:

$$\frac{\hat{t}}{1-\hat{t}}=\frac{\xi_2}{-\varepsilon_{l_2t}+\varepsilon_{c_1t}\frac{\varepsilon_{l_2R}}{\varepsilon_{c_1R}}}>0. \tag{40}$$

The expression for the optimal labor tax illuminates the trade-off between insurance (numerator) and incentives (denominator). The optimal labor tax increases with the insurance characteristic of labor income. The more risky is second-period labor income, the larger is ξ_2, and the larger are the social gains from insurance. The optimal labor tax decreases with the compensated tax elasticity of labor supply. The higher is the elasticity $\varepsilon_{l_2t}<0$ in absolute value, the more labor supply responds to taxation, and the lower should be the optimal labor tax rate. From the denominator in the expression for social insurance follows that capital taxes allow for more social insurance – ceteris paribus ξ_2 – if labor income is a stronger substitute for savings, i.e., when $\frac{\varepsilon_{l_2R}}{\varepsilon_{c_1R}}>0$ is larger. By taxing capital income, the government reduces moral hazard in social insurance, and optimal labor taxes can be set higher accordingly. Thus, positive capital income taxes allow for more social insurance. When the government would not be interested in providing social insurance ($\xi_2=0$) both the labor and capital tax would be zero.

Note that the capital tax is optimally employed irrespective of the preference structure of the households. In particular, the elasticities are not zero even when preferences are separable and sub-utility over consumption is homothetic, cf. the elasticities in Table 1. These are the standard conditions to obtain zero optimal capital income taxes (no commodity tax differentiation) in deterministic models with linear instruments (cf. Sandmo, 1974; Atkinson and Stiglitz, 1976; Deaton, 1979; Atkinson and Sandmo, 1980). Hence, the Atkinson-Stiglitz no commodity tax-differentiation result breaks down under risk, as has been demonstrated before by Cremer and Gahvari (1995a).

Our analysis replicates the findings in Cremer and Gahvari (1995a), but sheds a different light on their explanation, which also affects the interpretation of optimal nonlinear policies in Cremer and Gahvari (1995b). Cremer and Gahvari (1995a) cast their model in terms of optimal commodity taxes rather than labor income and capital income taxes. They argue that commodity taxes should optimally be differentiated. In particular, the tax on the 'pre-committed' commodity (c_1) should be lower than that on the 'post-committed' commodity (c_2). This finding corresponds to our result of the desirability of capital income taxes.

Cremer and Gahvari (1995a,b) argue that commodity tax differentiation is optimal to reduce under- and over-consumption of pre- and post-committed goods. If this argument would be correct, there would be (precautionary) oversaving in our setting, which the government would like to correct by levying a tax on saving. We think that this explanation needs to be revised. In particular, if there is over- (under-)consumption, there would be an externality in consumption choices. Taxing (subsidizing) such goods would therefore raise social welfare. This is, however, not the case, since individuals optimally reduce their risk exposure through self-insurance in the form of precautionary saving. We have shown above that taxes on saving do not reduce income risk, since the saving tax base is deterministic. Levying a saving tax (and rebating the revenue in the form of transfers) would therefore not reduce the exposure of households to income risk, while at the same time it would create (larger) distortions in the saving decision. Hence, such a policy cannot be welfare improving. The reason why commodity tax differentiation is optimal is that such a policy alleviates moral hazard problems in social insurance. A capital tax therefore reduces the distortions on labor supply that are caused by the labor tax. Hence, it allows for more social insurance in Cremer and Gahvari (1995a,b) and in our model. Indeed, Lemma 1 in Cremer and Gahvari (1995a) implies complementarity between (second-period) labor supply and first-period consumption, like in our model.

Finally, if one interprets labor supply as the retirement decision, our results indicate that (retirement) savings should optimally be taxed as long as the labor tax directly distorts the retirement decision. Consequently, in an optimal social insurance scheme it is not desirable to have actuarially neutral pension saving schemes, i.e., a zero net tax on pension saving. Moreover, if the aim is to raise the effective retirement age, this could be indirectly achieved by increasing the tax burden on (pension) savings.

Proposition 1. (Exogenous first-period leisure) *The optimal capital tax is positive. The capital tax is not used for social insurance, but only to off-set distortions on second-period labor supply. The optimal capital tax increases with the complementarity between first-period consumption and second-period labor supply, and if capital taxes are less distortionary.*

5 Saving-for-retirement: exogenous second-period leisure

Our second special case is concerned with exogenous and non-stochastic second-period labor income: $\varepsilon_{l_2 t} = \varepsilon_{l_2 R} = \xi_2 = 0$. In this case, one can view first-period labor supply as working from the young and savings are made to finance retirement consumption only.

From equations (35) and (36), the expressions for the optimal taxes on labor income and saving are in this case given by

$$\omega\xi_1 = -\left(\frac{t+\tau r/R}{1-t}\right)\omega\varepsilon_{l_1t} + \left(\frac{\tau r/R}{1-t}\right)\gamma\varepsilon_{c_1t}, \tag{41}$$

$$\omega\xi_1 = \left(\frac{t+\tau r/R}{1-t}\right)\omega\varepsilon_{l_1R} - \left(\frac{\tau r/R}{1-t}\right)\gamma\varepsilon_{c_1R}. \tag{42}$$

Equation (41) is the optimum condition of the labor tax where the effective marginal insurance benefits ($\omega\xi_1 > 0$), are equated with the marginal efficiency costs of the labor tax. The net marginal costs of employing a larger labor tax consist of two elements. First, increasing the labor tax results in larger labor market distortions that are represented by $-\left(\frac{t+\tau r/R}{1-t}\right)\omega\varepsilon_{l_1t} > 0$. Second, intertemporal distortions will be smaller when the labor tax increases as indicated by $\left(\frac{\tau r/R}{1-t}\right)\gamma\varepsilon_{c_1t} < 0$. Intuitively, the labor tax reduces first-period consumption demand, and this mitigates overconsumption in the first period resulting from a pre-existing, positive capital income tax. When the capital income tax is zero, only the labor tax determines the distortions in labor supply.

Equation (42) is the optimum condition for the capital income tax. The marginal insurance benefits ($\omega\xi_1 > 0$) are equal to the marginal efficiency costs of the capital income tax. In contrast to the previous case (see section 4), the capital income tax now features insurance benefits, since savings are stochastic. Indeed, a larger variance in first-period income shocks gives a larger variance in savings, since individuals with lower first-period labor income save less. The costs of employing the capital tax for social insurance are two-fold. First, a larger capital income tax entails larger intertemporal distortions in consumption as indicated by $-\left(\frac{\tau r/R}{1-t}\right)\gamma\varepsilon_{c_1R} > 0$. This term was also present before. Second, a larger capital income tax exacerbates the labor tax distortions by acting as an implicit tax on labor supply as can be seen from $\left(\frac{t+\tau r/R}{1-t}\right)\omega\varepsilon_{l_1R} > 0$. Intuitively, the capital tax reduces first-period labor supply, since intertemporal substitution in consumption provokes a wealth effect on leisure demand in period one. The capital tax also affects labor supply via the tax wedge on labor. In particular, the capital tax changes the relative price of first-period labor supply in terms of second-period consumption. The capital tax did not feature in the tax wedge on labor in the previous model, because the capital tax does not affect the relative price of second-period labor supply in terms of second-period consumption. Again, there is no direct intertemporal substitution in leisure, since individuals consume leisure only in the first-period.

Compared to the previous model, the cross-elasticity of labor supply with respect to the net interest rate has switched in sign. A larger capital tax lowers the net return on saving and raises first-period consumption relative to second-period consumption. As a result, individuals would like to substitute first-period consumption for first-period leisure and first-period labor supply falls. Consequently, saving and first-period labor supply are complements. Capital income taxes therefore do not reduce labor market distortions, but exacerbate them. Indeed, reducing labor market distortions ceteris paribus requires subsidies on capital income rather than taxes.

The insurance characteristic is identical in the expressions for both the labor and the capital tax. Hence, insuring income through either labor or capital taxes provides the same distributional benefits. The reason is that the marginal propensity to save out of first-period labor income is equal to one, given that the first-period consumption and labor supply choices are committed before the earnings shock is realized. Consequently, a tax on saving is equivalent to a tax on labor income in terms of reducing the variance in earnings. Thus, whether labor income should be taxed at a higher rate than capital income depends only on whether the marginal costs of employing labor taxes are lower than the marginal costs of employing capital income taxes. Therefore, an optimal policy equalizes the marginal excess burdens of labor and capital taxes.

We obtain the optimal Ramsey-rule for the dual income tax structure by subtracting equations (41) and (42) to find

$$\left(\frac{\hat{\tau}r/\hat{R}}{1-\hat{t}}\right)\gamma\left(\varepsilon_{c_1t}+\varepsilon_{c_1R}\right)=\left(\frac{\hat{t}+\hat{\tau}r/\hat{R}}{1-\hat{t}}\right)\omega\left(\varepsilon_{l_1t}+\varepsilon_{l_1R}\right). \tag{43}$$

Our Ramsey-rule is intuitively the same as the optimal dual income tax in deterministic Ramsey models with saving for retirement (see, e.g., Atkinson and Sandmo, 1980, equation (32)), but now in case of providing optimal social insurance, rather than raising an exogenous amount of tax revenue with distorting tax instruments.[8]

The left-hand side represents the marginal welfare costs of employing the capital income tax for income insurance. The cost of the capital tax increase with the tax wedge on capital income $\frac{\hat{\tau}r/\hat{R}}{1-\hat{t}}$, and the total elasticity of first-period consumption $\gamma(\varepsilon_{c_1t}+\varepsilon_{c_1R})<0$, which measures the behavioral response of the savings base with respect to both tax instruments combined. Both elasticities are negative. A higher capital tax distorts saving by boosting first-period consumption. Additionally, a higher labor tax counters the saving distortion by reducing first-period consumption. $\varepsilon_{c_1t}+\varepsilon_{c_1R}$ gives the combined effect of a higher capital tax while simultaneously reducing the labor tax. This term is always negative.

Similarly, the right-hand side gives the welfare cost of using the labor income tax. The cost of the labor tax increase with the net tax wedge on labor supply $\frac{\hat{t}+\hat{\tau}r/\hat{R}}{1-\hat{t}}$, and the total elasticity of the labor tax base $\omega(\varepsilon_{l_1t}+\varepsilon_{l_1R})$ with respect to the two policy instruments.

[8]Note that there is an important difference with Atkinson and Sandmo (1980) in the optimal tax formula, which is due to the fact that we cannot employ the symmetry of the Slutsky matrix. Consequently, in our optimal Ramsey-rule the terms in brackets contain the elasticity of one tax base with respect to all policy instruments employed, rather than the elasticity of all tax bases with respect to one policy instrument employed.

At first sight, the tax base elasticity appears ambiguous. On the one hand, an increase in labor taxation will decrease labor supply: $\varepsilon_{l_1t} < 0$. On the other hand, an increase in the net interest rate boosts labor supply: $\varepsilon_{l_1R} > 0$. By substituting the elasticities (see Table 1), we find that the net effect is always negative: $\varepsilon_{l_1t} + \varepsilon_{l_1R} = -\frac{\varepsilon_1 \Sigma_1}{\Delta} \frac{\gamma}{1-t} < 0$ (for $\varepsilon_2 = 0$). Intuitively, to reduce labor supply distortions the government would like to provide a saving subsidy. However, the increase in labor taxes needed to finance the capital subsidy exacerbates the labor supply distortions, which would more than off-set the positive effect of the capital subsidy on labor supply.

Both tax wedges have the same sign at the optimum. Distortions in first-period labor by a non-zero total tax wedge on labor supply should be equal to the distortions in saving by a non-zero tax wedge on saving. Therefore, capital income is optimally taxed (subsidized) at a positive rate $\hat{\tau}r/\hat{R} > 0$ (< 0) if labor income is taxed (subsidized) on a net basis, i.e., if $\frac{\hat{t}+\hat{\tau}r/\hat{R}}{1-\hat{t}} > 0$ (< 0). Below we demonstrate that the net tax on labor is always positive so that capital income should always be taxed. Intuitively, starting from a situation without taxes on capital income, introducing a small tax on capital income, while lowering the labor tax at the same time, would produce no change in insurance benefits, since both instruments have identical insurance gains. Also, starting from a zero capital tax, the introduction of a small capital tax would only generate second-order intertemporal distortions in consumption. However, it would allow for a first-order reduction in distortions in labor supply by lowering the labor tax. Thus, taxing capital income helps to achieve the same insurance at lower efficiency costs.

In the current setting the Atkinson-Stiglitz zero commodity-tax result can also never be obtained as long as standard utility functions are adopted. In particular, zero taxation of capital income would require either that first-period consumption is zero ($\gamma = 0$), first-period consumption is infinitely elastic ($\rho_1 \equiv \infty$), or first-period labor supply is completely inelastic ($\varepsilon_1 = 0$), cf. the elasticities in Table 1. In these knife-edge cases the capital tax is either infinitely distortionary or the labor tax is completely non-distortionary. Hence, in stark contrast to the deterministic Ramsey-models, positive taxation of capital income is unambiguously part of the optimal tax policy under income risk.

By substituting (43) into the reduced first order conditions (41) and (42), and rearranging and collecting terms, we find that the total net tax on labor satisfies

$$\frac{\hat{t}+\hat{\tau}r/\hat{R}}{1-\hat{t}} = \frac{\xi_1 + \varepsilon_{c_1t}\frac{\xi_1}{\varepsilon_{c_1R}}}{-\varepsilon_{l_1t} + \varepsilon_{c_1t}\frac{\varepsilon_{l_1R}}{\varepsilon_{c_1R}}} > 0. \tag{44}$$

The optimal net tax on labor is positive by substituting the elasticities from Table 1. Equation (44) gives the standard trade-off between social insurance (numerator) and distortions (denominator) and proves that the capital income tax is optimally positive, cf. (43).

The denominator represents the net distortions of taxing labor, which decrease the optimal tax wedge on labor. In particular, distortions of social insurance increase with the tax-elasticity of labor supply $-\varepsilon_{l_1 t} > 0$. Like before, the second term in the denominator, $\varepsilon_{c_1 t}\frac{\varepsilon_{l_1 R}}{\varepsilon_{c_1 R}} > 0$, captures the interaction between labor supply and saving. The stronger the substitutability between first-period consumption and first-period labor supply, the larger (in absolute value) is $\frac{\varepsilon_{l_1 R}}{\varepsilon_{c_1 R}} < 0$. Thus, if capital taxes are higher, labor taxes should be lower as they exacerbate the distortions of the capital tax on labor supply. The interaction term is smaller if the cross-elasticity of consumption with respect to the labor tax ($\varepsilon_{c_1 t} < 0$) is smaller (in absolute value). In that case, a higher labor tax does not exacerbate labor supply distortions a lot.

The term in the numerator contains the standard, direct insurance gain of labor taxes $\xi_1 > 0$. In addition, there is also an indirect insurance gain of labor taxes, since $\varepsilon_{c_1 t}\frac{\xi_1}{\varepsilon_{c_1 R}} > 0$. Intuitively, the labor tax reduces first-period consumption $\varepsilon_{c_1 t} < 0$, and thereby reduces the distortions of the capital tax on consumption choices. As a result, the trade-off between insurance and distortions of employing capital taxes improves, as indicated by the term $\frac{\xi_1}{\varepsilon_{c_1 R}} < 0$. Therefore, if the labor tax improves the insurance-incentives trade-off of the capital tax, $\varepsilon_{c_1 t}\frac{\xi_1}{\varepsilon_{c_1 R}}$ is larger, and the optimal wedge on labor should increase accordingly.

By using the optimal tax wedge on labor (44) in the optimal dual tax structure in equation (43), we obtain the optimal capital tax rate

$$\frac{\hat{\tau} r/\hat{R}}{1-\hat{t}} = \frac{\omega}{\gamma}\left(\frac{\xi_1 + \varepsilon_{l_1 R}\frac{\xi_1}{\varepsilon_{l_1 t}}}{-\varepsilon_{c_1 R} + \varepsilon_{l_1 R}\frac{\varepsilon_{c_1 t}}{\varepsilon_{l_1 t}}}\right) > 0. \tag{45}$$

Upon substitution of the relevant elasticities from Table 1 we can derive that the optimal capital tax is indeed unambiguously positive and increases with the desire to insure risk in first-period income ξ_1. The larger the first-period labor income share relative to first-period consumption, the larger is $\frac{\omega}{\gamma}$, and the broader is the saving tax base compared to the labor tax base. Hence, for this mechanical reason the capital tax should optimally increase.

The denominator in brackets represents the welfare cost of the capital tax. Welfare losses of capital income taxes increase in the elasticity of consumption with respect to the interest rate ($-\varepsilon_{c_1 R} > 0$). Capital taxes exacerbate the distortions of the labor tax on labor supply, so that the efficiency losses in saving increase even more, cf. $\varepsilon_{l_1 R}\frac{\varepsilon_{c_1 t}}{\varepsilon_{l_1 t}} > 0$.

The first term in the numerator, ξ_1, designates the direct insurance gain of capital taxes, whereas $\varepsilon_{l_1 R}\frac{\xi_1}{\varepsilon_{l_1 t}} < 0$ represents again the indirect insurance effect. Capital taxes should be higher if this provides a lot of distributional benefits. However, by lowering first-period labor supply ($\varepsilon_{l_1 R} > 0$), capital income taxes worsen the insurance-incentives trade-off of the labor tax, which is captured by $\frac{\xi_1}{\varepsilon_{l_1 t}} < 0$. As a result, capital income taxes reduce the attractiveness of using labor income taxes to insure income risks, and should be lowered accordingly.

We can eliminate $\frac{\tau r}{R}$ from the optimal wedge on labor supply in equation (44) to find the optimal labor tax

$$\frac{\hat{t}}{1-\hat{t}} = \left(\frac{1 + \frac{\varepsilon_{c_1 t}}{\varepsilon_{c_1 R}} - \frac{\frac{\omega}{\gamma}\left(\varepsilon_{l_1 t} + \varepsilon_{l_1 R}\right)}{\varepsilon_{c_1 R}}}{-\varepsilon_{l_1 t} + \varepsilon_{c_1 t}\frac{\varepsilon_{l_1 R}}{\varepsilon_{c_1 R}}} \right) \xi_1. \tag{46}$$

The labor tax is generally ambiguous in sign. The reason is that the capital tax is part of the labor wedge. If the optimal capital tax becomes larger, a negative labor tax $t < 0$ might be necessary in order maintain the optimal net tax wedge on labor ($\frac{t+\tau r}{1-t} > 0$). The condition for optimally positive labor taxes is $\omega\left(\varepsilon_{l_1 t} + \varepsilon_{l_1 R}\right) > \gamma(\varepsilon_{c_1 t} + \varepsilon_{c_1 R})$. This condition will be fulfilled if first-period labor supply is sufficiently inelastic (ε_1):

$$1 - \frac{\gamma}{\omega}\left(\frac{\varepsilon_{c_1 t} + \varepsilon_{c_1 R}}{\varepsilon_{l_1 t} + \varepsilon_{l_1 R}}\right) = 1 - (1-t)(1-\pi_1) - \frac{1-\gamma}{\rho_2 \Sigma_1 \varepsilon_1 \omega} < 0, \tag{47}$$

We assume that this condition holds and that the labor tax is optimally positive. Note however that the sign of the capital tax does not depend on this assumption, so the result that capital income should optimally be taxed remains unchanged.

To conclude, subsidies on saving could boost labor supply of the young workers in the saving-for-retirement model. However, this is not an optimal policy. A negative capital tax raises the exposure to labor income risk. Hence, a rise in the labor tax is needed to maintain the same level of insurance. Intuitively, keeping the level of income insurance constant implies that the labor tax needs to increase as the capital tax is lowered. However, a negative capital tax combined with a higher labor tax so as to keep the level of social insurance constant generates larger distortions. The reason is that the rise in the labor tax more than off-sets the positive impact of the saving subsidy on labor supply. Consequently, capital income (i.e., retirement income in this context) should not be subsidized, but taxed so as to provide social insurance at the lowest social cost. Therefore, these results suggest that policies to subsidize retirement plans are questionable, because the distortions associated with a rise in the tax burden to finance the tax-subsidies outweigh their beneficial effects on labor supply.

Proposition 2. (Exogenous second-period leisure) *The optimal capital tax is positive. It is equally effective as the labor tax in providing social insurance. The optimal capital tax increases i) with the desire to insure income risk and, ii) when capital taxes are less distortionary compared to labor taxes, i.e., when intertemporal distortions in consumption are small, substitutability between first-period labor supply and first-period consumption is small, and the labor supply elasticity is large.*

6 General model

In the general model, in which labor supply in both periods is endogenous, we have the following expression describing the optimal labor tax from rearranging equation (35):

$$\omega\xi_1 + (1-\omega)\xi_2 = -\left(\frac{t+\tau r/R}{1-t}\right)\omega\varepsilon_{l_1 t} - \left(\frac{t}{1-t}\right)(1-\omega)\varepsilon_{l_2 t} + \left(\frac{\tau r/R}{1-t}\right)\gamma\varepsilon_{c_1 t} \tag{48}$$

The expression for the optimal labor tax equates the insurance gains of reducing risk in first- and second period incomes, $\omega\xi_1 + (1-\omega)\xi_2$, to the net marginal cost of doing so. The welfare costs of labor taxes are represented by three terms. The first two terms give the marginal excess burdens of labor taxes on first- and second period labor supply, respectively. Note that $-\omega\varepsilon_{l_1 t} > 0$, and $-(1-\omega)\varepsilon_{l_2 t} > 0$. The last term gives the reduction in the excess burden of a positive capital tax, since the labor tax partially off-sets the saving distortion by discouraging first-period consumption ($\gamma\varepsilon_{c_1 t} < 0$).

The optimal capital tax follows from rearranging equation (36):

$$\omega\xi_1 = \left(\frac{t+\tau r/R}{1-t}\right)\omega\varepsilon_{l_1 R} + \left(\frac{t}{1-t}\right)(1-\omega)\varepsilon_{l_2 R} - \left(\frac{\tau r/R}{1-t}\right)\gamma\varepsilon_{c_1 R}. \tag{49}$$

Note that, in contrast to the labor income tax, the capital tax can only be employed for insurance reasons to reduce the risk of first-period incomes ($\omega\xi_1$), not second-period incomes ($(1-\omega)\xi_2$). The reason is that the second-period income shock occurs after savings have been made. Hence, taxing savings does not help to reduce the variance of incomes in the second period of the life-cycle. The marginal insurance gains $\omega\xi_1$ should again be equal to the net marginal dead weight loss associated with more income insurance. In particular, a capital tax causes the standard saving distortion which is represented by $-\frac{\tau r/R}{1-t}\gamma\varepsilon_{c_1 R} > 0$. Moreover, the capital tax exacerbates the labor tax distortions on first-period labor supply since $\omega\varepsilon_{l_1 R} > 0$. This is, first, due to wealth effects arising from intertemporal substitution in consumption. Second, in the general model with endogenous labor supply in both periods, capital taxes also generate direct intertemporal substitution effects on leisure demands so that first-period labor supply falls. Finally, the capital tax reduces distortions in second-period labor supply, because $\frac{t}{1-t}(1-\omega)\varepsilon_{l_2 R} < 0$ for positive labor taxes. Wealth effects due to intertemporal substitution in consumption and intertemporal substitution in leisure both raise second-period labor supply.

By combining both equations we obtain the optimal dual tax structure:

$$\left(\frac{\hat{\tau} r/R}{1-\hat{t}}\right)\gamma\left(\varepsilon_{c_1 t} + \varepsilon_{c_1 R}\right) = \left(\frac{\hat{t}+\hat{\tau} r/R}{1-\hat{t}}\right)\omega\left(\varepsilon_{l_1 t} + \varepsilon_{l_1 R}\right) + \left(\frac{\hat{t}}{1-\hat{t}}\right)(1-\omega)\left(\varepsilon_{l_2 t} + \varepsilon_{l_2 R}\right) + (1-\omega)\xi_2 \tag{50}$$

The optimal capital tax is determined by four elements. The two elements in the first line are identical to the expression for the optimal capital tax of the previous section, see equation (43).

First, the optimal capital income tax $\frac{\hat{r}r/R}{1-\hat{t}}$ is larger if first-period consumption has a lower total elasticity with respect to the policy instruments and the income share of consumption today is lower (lower γ), so that $\gamma\left(\varepsilon_{c_1t}+\varepsilon_{c_1R}\right)<0$ is lower in absolute value. Naturally, the capital tax distorts intertemporal consumption choices ($\varepsilon_{c_1R}<0$). In addition, the labor tax reduces the capital tax distortions by reducing overconsumption in the first period ($\varepsilon_{c_1t}<0$) – provided that the capital tax is positive. The net effect is negative, see also the previous section.

Second, the optimal capital tax increases if first-period labor is more heavily distorted, i.e., when $\left(\frac{\hat{t}+\hat{\tau}R}{1-\hat{t}}\right)\omega\left(\varepsilon_{l_1t}+\varepsilon_{l_1R}\right)$ is higher in absolute value. Note that the distortion is larger if individuals earn a relatively large fraction of their life-time income ω in the first period. The intuition for this term is identical to the model with only endogenous first-period labor supply. In particular, a capital subsidy could be employed to reduce the labor tax distortion. However, the rise in labor taxes to maintain the same level of income insurance could more than off-set the positive effects of the capital subsidy on labor supply. In contrast to the previous section the net effect is no longer unambiguous, since $\varepsilon_{l_1t}+\varepsilon_{l_1R}=-\frac{\varepsilon_1\Sigma_1}{\Delta}\left(\frac{\gamma}{1-t}-\rho_1(1-\pi_2)(1-\omega)\varepsilon_2\right)\gtrless 0$. Intuitively, in the current model with endogenous leisure in both periods, intertemporal substitution effects in the pattern of leisure demand over time provide an additional channel whereby capital income taxes affect labor supply, besides the wealth effects generated by intertemporal substitution in consumption. In particular, a larger capital income tax renders current leisure more attractive than future leisure. As a result, the capital tax raises the distortion on first-period labor supply even further, thereby reducing the desire to tax capital incomes. This intertemporal substitution effect in leisure is absent in the models with only one leisure demand decision. Hence, only if intertemporal substitution effects in leisure are sufficiently small, a positive capital tax alleviates the labor-tax distortions on first-period labor supply.

Third, $\frac{\hat{t}}{1-\hat{t}}(1-\omega)\left(\varepsilon_{l_2t}+\varepsilon_{l_2R}\right)<0$ indicates the role of capital taxes to reduce the tax distortion on second-period labor supply. The combined elasticity is unambiguously signed: $\varepsilon_{l_2t}+\varepsilon_{l_2R}<0$. A larger capital tax allows for a lower labor tax, so that labor tax distortions on second-period labor supply diminish. In addition, a capital tax boosts second-period labor supply through intertemporal substitution effects so that it alleviates the distortions of the labor tax on second-period labor supply even more. Accordingly, a positive capital tax ceteris paribus allows for more social insurance by reducing the distortions in second-period labor supply.

Fourth, the capital tax increases if labor taxes are less efficient in social insurance, thus, if $(1-\omega)\xi_2$ is lower, i.e, if second-period risk is relatively less important compared to first-period income risk (note that the previous three terms discussed so far are negative.) Indeed, in the absence of second-period labor income risk (ξ_2), capital income is generally taxed at positive rates if intertemporal substitution of leisure is modest and if labor supplies in both periods are taxed at net positive rates. Consequently, capital income taxes help to reduce moral hazard in social insurance. However, if second-period labor income is substantially more risky than first-period income, ξ_2 is larger, and capital income taxes loose their attractiveness as an insurance device. Therefore, capital income taxes tend to be set lower.

We can derive an explicit condition under which capital income should be taxed at positive rates when capital taxes do not provide insurance at all, i.e., if the saving base is deterministic. Capital income taxes are then employed for efficiency reasons only. In that case, we can set $\xi_1 = 0$ in the expression for the optimal capital tax (49) to find

$$\frac{\hat{\tau} r}{\hat{R}} = \left(\frac{\omega \varepsilon_{l_1 R} + (1-\omega)\varepsilon_{l_2 R}}{\gamma \varepsilon_{c_1 R} - \omega \varepsilon_{l_1 R}} \right) \hat{t}. \tag{51}$$

Capital income is taxed if labor income is taxed ($t > 0$), and the positive effect of capital income taxes on second-period labor supply ($(1-\omega)\varepsilon_{l_2 R} < 0$) is larger than the negative effect of capital income taxes on first-period labor supply ($\omega \varepsilon_{l_1 R} > 0$). The denominator is always negative. The net effect thus depends on the intertemporal substitution pattern in labor supply and the relative shares of labor earned in the first- and the second-period of the life-cycle (ω). Theoretically, the sign of the capital tax is ambiguous. If the major part of income would be earned in the first period, i.e, if ω was high, and if first-period labor supply was very sensitive to changes in the interest rate, i.e., if there would be strong intertemporal substitution effects in leisure, then we might have $\omega \varepsilon_{l_1 R} + (1-\omega)\varepsilon_{l_2 R} > 0$, so that we obtain a case where saving would be optimally subsidized. Therefore, a model where income risk is only due to (disability or health) risk when old and where the government is mainly concerned with fostering labor supply of younger workers could motivate real world tax reliefs (or even direct subsidies) on retirement benefits, as, e.g., in the case of IRA accounts in the U.S. or of "Riester-Rente" in Germany.

Given hump-shaped earnings profiles, second-period labor income is typically more important than first-period labor income, hence $\omega < 1/2$. There is little empirical evidence on the cross-elasticities of labor supply with respect to the net interest rate. In realistically calibrated life-cycle models Erosa and Gervais (2002) and Conesa et al. (2009) find that optimal capital taxes are generally positive for efficiency reasons as a result of intertemporal substitution effects in leisure only. In particular, the capital tax reduces labor supply at earlier stages of the life-cycle more than the increases in labor supply at later stages. This evidence suggests, therefore, that $\omega \varepsilon_{l_1 R} + (1-\omega)\varepsilon_{l_2 R} < 0$. Accordingly, capital income should optimally be taxed, even if capital income taxes do not provide any insurance gains.

Returning to the general case of skill shocks in both periods of the life-cycle, we find the optimal capital tax rate from solving equation (49) for the labor tax $\frac{t}{1-t}$ and substituting the resulting expression into equation (48). Collecting terms and rearranging then delivers

$$\frac{\hat{\tau}r/\hat{R}}{1-\hat{t}} = \frac{\omega\xi_1 + \bar{\varepsilon}_{lR}\frac{[\omega\xi_1+(1-\omega)\xi_2]}{\bar{\varepsilon}_{lt}}}{\varepsilon_{aR} - \bar{\varepsilon}_{lR}\frac{\varepsilon_{at}}{\bar{\varepsilon}_{lt}}} > 0, \tag{52}$$

where $\bar{\varepsilon}_{lR} = \omega\varepsilon_{l_1R} + (1-\omega)\varepsilon_{l_2R}$ and $\bar{\varepsilon}_{lt} = \omega\varepsilon_{l_1t} + (1-\omega)\varepsilon_{l_2t} < 0$ denote the income-weighted average elasticities of total labor supply with respect to the interest factor and the labor tax rate. According to the discussion in the last paragraph, we maintain the assumption that $\bar{\varepsilon}_{lR} = \omega\varepsilon_{l_1R} + (1-\omega)\varepsilon_{l_2R} < 0$. The expression $\varepsilon_{aR} \equiv \omega\varepsilon_{l_1R} - \gamma\varepsilon_{c_1R} > 0$ denotes the compensated interest rate elasticity of savings. It is unambiguously positive, because a higher net interest rate increases first-period labor supply ($\varepsilon_{l_1R} > 0$) and decreases first-period consumption ($\varepsilon_{c_1R} < 0$). $\varepsilon_{at} \equiv \omega\varepsilon_{l_1t} - \gamma\varepsilon_{c_1t}$ is the elasticity of saving with respect to the labor tax. If $\varepsilon_{at} > 0$ ($\varepsilon_{at} < 0$), saving increases (decreases) as a result of labor taxation. The sign of ε_{at} is ambiguous since labor taxation both reduces labor supply ($\omega\varepsilon_{l_1t} < 0$) and first-period consumption ($\gamma\varepsilon_{c_1t} < 0$).

By assuming that $\bar{\varepsilon}_{lR} < 0$, (52) demonstrates that the optimal capital tax is positive in the general case as well.[9,10] The first term in the denominator represents the direct distortions in savings, i.e., intertemporal distortions in first-period consumption and in first-period labor supply, respectively. The larger are direct intertemporal distortions on consumption and leisure, the larger is $\varepsilon_{aR} > 0$, and the lower the optimal capital tax should be. Again, a complementarity-effect between saving and labor supply is at work. This effect is captured by the last term in the denominator. Labor taxation mitigates distortions in savings, if labor taxes boost savings ($\varepsilon_{at} > 0$), but distort labor supply ($\bar{\varepsilon}_{lt} < 0$). This trade-off is represented by $\frac{\varepsilon_{at}}{\bar{\varepsilon}_{lt}}$. If $\varepsilon_{at} > 0$ capital taxation boosts labor supply ($\bar{\varepsilon}_{lR} < 0$), and thereby alleviates the distortions of the labor tax on labor supply. Therefore, capital taxes should be set higher. If, instead, $\varepsilon_{at} < 0$, a higher capital tax exacerbates the savings distortions of the labor tax by boosting life-time labor supply. Thus, $\bar{\varepsilon}_{lR}\frac{\varepsilon_{at}}{\bar{\varepsilon}_{lt}} < 0$, and capital taxation should decrease for $\varepsilon_{at} < 0$.

The numerator of equation (52) captures the insurance effects of capital taxes and consists of two parts. First, there is the direct insurance effect $\omega\xi_1$. If taxing savings reduces the exposure to first-period income risk more, capital income taxes should be higher. This is analogous to the explanation in the saving-for-retirement case in section 5. Additionally, the indirect insurance effect is at work. In particular, if the capital tax boosts labor supply, $\bar{\varepsilon}_{lR} < 0$, the capital tax improves the insurance-incentives trade-off of the labor tax, since $\frac{[\omega\xi_1+(1-\omega)\xi_2]}{\bar{\varepsilon}_{lt}} < 0$. As a result the labor tax becomes a more attractive

[9] Second-order conditions for the optimal tax problem ensure that the denominator of the optimal tax expression is positive.

[10] Note that the term exactly simplifies to the optimal capital tax rule (45), if second-period labor supply is inelastic ($\varepsilon_{l_2t} = \varepsilon_{l_2R} = 0$), and if there is no risk in the second period ($\xi_2 = 0$).

instrument for social insurance, and the capital tax should optimally increase.

To derive the optimal labor tax, we insert equation (52) into equation (49) and collect terms in order to receive

$$\frac{t}{1-t} = \frac{\omega\xi_1 + (1-\omega)\xi_2 + \varepsilon_{at}\frac{\omega\xi_1}{\varepsilon_{aR}}}{-\bar{\varepsilon}_{lt} + \varepsilon_{at}\frac{\bar{\varepsilon}_{lR}}{\varepsilon_{aR}}}. \tag{53}$$

The denominator shows that the optimal labor tax falls if providing social insurance is more distortionary. The labor tax distorts labor supply as represented by the average labor supply elasticity ($\bar{\varepsilon}_{lt} < 0$). However, the labor tax is larger if the capital tax is helpful in reducing labor market distortions by indirectly boosting labor supply ($\bar{\varepsilon}_{lR} < 0$), and if the labor tax strengthens the complementarity-effect $\frac{\bar{\varepsilon}_{lR}}{\varepsilon_{aR}} < 0$ by raising savings ($\varepsilon_{at} > 0$). Instead, if the labor tax reduces overall saving ($\varepsilon_{at} < 0$), it weakens the complementarity-effect of capital taxation. Consequently, distortions from labor taxation will be exacerbated, and the labor tax should be set at a lower rate. The numerator reveals that the optimal labor tax increases with the desire to insure income risk in both periods ($\omega\xi_1 + (1-\omega)\xi_2$). Finally, there is the indirect insurance effect of the tax policy. If ε_{at} is positive, the labor tax improves the insurance-incentives trade-off of the capital tax. As a result, the optimal tax on labor income needs to be higher as a result. The reverse reasoning holds if $\varepsilon_{at} < 0$. Proposition 3 summarizes the results of this section.

Proposition 3. (Leisure endogenous in both periods) *The capital tax is optimally positive if there is weak intertemporal substitution in leisure demands over the life-cycle and the disadvantages of capital taxes over labor taxes to insure income risk are small, i.e., if labor income risks occur mainly at the beginning of the life-cycle. The capital tax is employed for both insurance and efficiency reasons. The capital tax directly insures first-period labor income risk. In addition, the capital tax allows for a lower total marginal tax burden on first-period labor supply – for given levels of insurance – and reduces moral hazard in second-period labor supply.*

7 Conclusions

This paper has demonstrated that capital income is generally taxed in a standard two-period life-cycle model with non-insurable risks in both periods of the life-cycle. The Atkinson-Stiglitz theorem of non-differentiation of commodity taxes breaks down under risk. Intuitively, capital income taxes boost second-period labor supply by making future leisure more costly. Taxing capital income thus reduces moral hazard in second-period labor supply (or retirement). However, capital income taxes reduce first-period labor supply, but this effect is generally off-set because capital taxes also allow for a lower level of labor taxation. Indeed, optimal social insurance requires that distortions associated with insurance should be smoothed over labor income and saving bases.

This paper employed linear policy instruments and confirmed results from the new dynamic public finance literature where rich sets of non-linear instruments are analyzed, see for example Golosov et al. (2003), Kocherlakota (2005), Golosov et al. (2006), and Diamond (2006), Albanesi and Sleet (2006), and Golosov and Tsyvinski (2006). All these papers emphasize that intertemporal wedges are optimal to relax the incentive constraints associated with social insurance. By introducing intertemporal wedges in consumption choices, individuals with favorable skill-shocks are less tempted to mimic individuals with unfavorable skill-shocks. We show that this main intuition is applicable as well with linear tax instruments. Capital income taxes are desirable to reduce moral hazard in social insurance. In contrast to the non-linear policy instruments, we have also demonstrated that capital taxes have a direct role in insuring labor market risks, especially when labor risks are important in the early stages of the life-cycle. This finding is similar to the desirability of indirect instruments for redistributional reasons, besides optimally employing a linear income tax in optimal redistribution models, cf. Atkinson and Stiglitz (1976).

Our findings have large policy relevance for the debate on the tax treatment of pension savings and stimulating later retirement. We show that (retirement) saving should generally be taxed, and not subsidized. Consequently, actuarially fair retirement schemes are not optimal. Governments should not try to subsidize retirement saving so as to reduce future public spending on state pensions or health care. By doing this, sustainability problems in public finances worsen rather than improve, since the government needs to raise the tax burden on working-age individuals, which results in larger labor market distortions and smaller tax bases – as long as governments do not wish to sacrifice on social insurance. Moreover, subsidies on (pension) saving increase moral hazard in social insurance by boosting the incentives to retire earlier. Hence, a policy of subsidies on (retirement) savings does not help to delay retirement either.

Appendix – Deriving compensated elasticities under risk

To derive the compensated elasticities we log-linearize the first-order conditions and the expected utility function, where we set the change in the latter to zero. We focus on the elasticities of expected consumption and labor supply in both periods with respect to deterministic (expected) changes in policies. Hence, we can employ the concept of global risk aversion (see, e.g., Varian, 1992, p. 380). We define global relative risk aversion in consumption as $\rho_i \equiv -\frac{\mathrm{E}[u_i''(c_i)]\mathrm{E}[c_i]}{\mathrm{E}[u_i'(c_i)]} > 0$. $\varepsilon_i \equiv \frac{\mathrm{E}[v_i''(l_i)]\mathrm{E}[\theta_i l_i]}{\mathrm{E}[v_i'(l_i)]\mathrm{E}[\theta_i]} > 0$ is a measure for the expected compensated labor supply elasticity in period $i = 1, 2$.

The log-linearized utility function is given by

$$c_1 u_1' \tilde{c}_1 - l_1 v_1' \tilde{l}_1 + \beta \mathrm{E}[c_2]\mathrm{E}[u_2']\tilde{c}_2 - \beta \frac{\mathrm{E}[\theta_2 l_2]}{\mathrm{E}\left[\theta_2\right]}\mathrm{E}[v_2']\tilde{l}_2 = 0, \tag{54}$$

where a tilde ($\tilde{}$) denotes a relative change, e.g., $\tilde{c}_i \equiv \frac{\mathrm{E}[dc_i]}{\mathrm{E}[c_i]}$ is the relative change in the expected value of c_i, and $\tilde{l}_i \equiv \frac{\mathrm{E}[d(\theta_i l_i)]}{\mathrm{E}[\theta_i l_i]}$ is the relative change in l_i, and where we used that fact that $\mathrm{E}[d(\theta_2 l_2)] = \mathrm{E}[\theta_2]\mathrm{E}[dl_2]$, because we are evaluating the change for a given θ_1 and because l_2 is chosen before θ_2 realizes.

Substituting the households' first-order conditions for labor supply and consumption in the linearized utility function, we find, after rearranging,

$$Rc_1\tilde{c}_1 + \mathrm{E}[c_2]\tilde{c}_2 - (1-\pi_1)(1-t)R\mathrm{E}\left[\theta_1\right] l_1 \tilde{l}_1 - \mathrm{E}[\theta_2 l_2]\left(1-\pi_2\right)(1-t)\tilde{l}_2 = 0. \tag{55}$$

Hence,

$$\gamma \tilde{c}_1 + (1-\gamma)\tilde{c}_2 - (1-\pi_1)(1-t)\omega \tilde{l}_1 - (1-\pi_2)(1-t)(1-\omega)\tilde{l}_2 = 0. \tag{56}$$

We defined $\gamma \equiv \frac{Rc_1}{R\mathrm{E}[\theta_1]l_1 + \mathrm{E}[\theta_2 l_2]}$ and $(1-\gamma) = \frac{\mathrm{E}[c_2]}{R\mathrm{E}[\theta_1]l_1 + \mathrm{E}[\theta_2 l_2]}$ as the expected expenditure shares of consumption in both periods and $\omega \equiv \frac{R\mathrm{E}[\theta_1]l_1}{R\mathrm{E}[\theta_1]l_1 + \mathrm{E}[\theta_2 l_2]}$ and $1-\omega \equiv \frac{\mathrm{E}[\theta_2 l_2]}{R\mathrm{E}[\theta_1]l_1 + \mathrm{E}[\theta_2 l_2]}$ as the expected share of labor income in period $i = 1, 2$ in total labor income (before taxes).

Log-linearizing the first-order conditions (before introducing the π_i-terms in labor supply) yields

$$\frac{u_1'' c_1}{u_1'}\tilde{c}_1 = \tilde{R} + \frac{\mathrm{E}[u_2'']\mathrm{E}[c_2]}{\mathrm{E}[u_2']}\tilde{c}_2, \tag{57}$$

$$\frac{v_1'' l_1}{v_1'}\tilde{l}_1 = -\tilde{t} + \tilde{R} + \frac{\mathrm{E}[u_2''\theta_1]\mathrm{E}[c_2]}{\mathrm{E}[u_2'\theta_1]}\tilde{c}_2, \tag{58}$$

$$\frac{\mathrm{E}[v_2'']\mathrm{E}[l_2]}{\mathrm{E}[v_2']}\frac{dl_2}{\mathrm{E}[d(\theta_2 l_2)]}\frac{\mathrm{E}[\theta_2 l_2]}{\mathrm{E}[l_2]}\tilde{l}_2 = -\tilde{t} + \frac{\mathrm{E}[u_2''\theta_2]\mathrm{E}[c_2]}{\mathrm{E}[u_2'\theta_2]}\tilde{c}_2. \tag{59}$$

Substituting the definitions of (global) relative risk aversion into equation (57) delivers

$$\tilde{c}_2 = \frac{\rho_1}{\rho_2}\tilde{c}_1 + \frac{1}{\rho_2}\tilde{R}. \tag{60}$$

Relying on Steiner's Rule for covariances, we find

$$\mathrm{E}[u_2''\theta_i] = \mathrm{E}\left[\theta_i\right]\mathrm{E}[u_2''] + cov\left[u_2'', \theta_i\right] = (1-\pi_i')\mathrm{E}\left[\theta_i\right]\mathrm{E}[u_2''], \tag{61}$$

$$\mathrm{E}[u_2'\theta_i] = \mathrm{E}\left[\theta_i\right]\mathrm{E}[u_2'] + cov\left[u_2', \theta_i\right] = (1-\pi_i)\mathrm{E}[\theta_i]\mathrm{E}[u_2'], \tag{62}$$

where $\pi_i' = -\frac{cov[u_2'',\theta_i]}{E[u_2'']E[\theta_i]} > 0$, as long as we assume non-increasing absolute risk aversion ($u_2''' > 0$). Since the π_i' terms are normalized covariances, they are always smaller than or equal to one: $0 \leq \pi_i \leq 1$.

Substituting these expressions into equations (58) and (59), we find

$$\frac{v_1'' l_1}{v_1'}\tilde{l}_1 = -\tilde{t} + \tilde{R} + \frac{(1-\pi_1')}{(1-\pi_1)}\frac{E[u_2'']E[c_2]}{E[u_2']}\tilde{c}_2, \tag{63}$$

$$\frac{E[v_2'']E[l_2]}{E[v_2']}\frac{dl_2}{E[d(\theta_2 l_2)]}\frac{E[\theta_2 l_2]}{E[l_2]}\tilde{l}_2 = -\tilde{t} + \frac{(1-\pi_2')}{(1-\pi_2)}\frac{E[u_2'']E[c_2]}{E[u_2']}\tilde{c}_2. \tag{64}$$

Using the definitions of the labor supply elasticities and rearranging yields

$$\tilde{l}_1 = \varepsilon_1\left(-\tilde{t} + \tilde{R}\right) - \Sigma_1\varepsilon_1\rho_2\tilde{c}_2, \tag{65}$$

$$\tilde{l}_2 = -\varepsilon_2\tilde{t} - \Sigma_2\varepsilon_2\rho_2\tilde{c}_2. \tag{66}$$

where $\Sigma_1 \equiv \frac{1-\pi_1'}{1-\pi_1} \geq 0$ and $\Sigma_2 \equiv \frac{1-\pi_2'}{1-\pi_2} \geq 0$, since $0 \leq \pi_i \leq 1$.

Together with the linearized Euler consumption equation and the linearized utility function we have a linear system of four equations in four unknowns which can be solved to find the elasticities. First, substitute the linearized Euler equation (60) in the other three linearized equations (56), (65), and (66) to find

$$\tilde{l}_1 = -\varepsilon_1\tilde{t} + \varepsilon_1(1-\Sigma_1)\tilde{R} - \Sigma_1\varepsilon_1\rho_1\tilde{c}_1, \tag{67}$$

$$\tilde{l}_2 = -\varepsilon_2\tilde{t} - \Sigma_2\varepsilon_2\tilde{R} - \Sigma_2\varepsilon_2\rho_1\tilde{c}_1, \tag{68}$$

$$(1-t)\sum_{i=1}^{2}(1-\pi_i)\omega_i\tilde{l}_i = (1-\gamma)\frac{1}{\rho_2}\tilde{R} + \left[\gamma + (1-\gamma)\frac{\rho_1}{\rho_2}\right]\tilde{c}_1. \tag{69}$$

Use the first two equations to substitute for $\tilde{l}_1$ and $\tilde{l}_2$ in the last equation to find the solution of the model for $\tilde{c}_1$:

$$\begin{aligned} & -\left[(1-\pi_1)\omega\varepsilon_1 + (1-\pi_2)(1-\omega)\varepsilon_2\right]\tilde{t} \\ & \left[-\frac{(1-\gamma)/\rho_2}{(1-t)} + (1-\pi_1)\omega\varepsilon_1(1-\Sigma_1) - (1-\pi_2)(1-\omega)\Sigma_2\varepsilon_2\right]\tilde{R} \\ = & \left[\frac{\gamma + (1-\gamma)\frac{\rho_1}{\rho_2}}{1-t} + (1-\pi_1)\omega\Sigma_1\varepsilon_1\rho_1 + (1-\pi_2)(1-\omega)\Sigma_2\varepsilon_2\rho_1\right]\tilde{c}_1. \end{aligned} \tag{70}$$

Using the last result in (67), (68) and (60) we can write the solution of the complete model as

$$\tilde{c}_1 = -\frac{\epsilon}{\Delta}\tilde{t} + \frac{\delta}{\Delta}\tilde{R}, \tag{71}$$

$$\tilde{c}_2 = -\frac{\rho_1}{\rho_2}\frac{\epsilon}{\Delta}\tilde{t} + \left[\frac{1}{\rho_2} + \frac{\rho_1}{\rho_2}\frac{\delta}{\Delta}\right]\tilde{R}, \tag{72}$$

$$\tilde{l}_1 = -\varepsilon_1\left[1 - \Sigma_1\frac{\rho_1\epsilon}{\Delta}\right]\tilde{t} - \varepsilon_1\Sigma_1\left[1 + \frac{\rho_1\delta}{\Delta} - \frac{1}{\Sigma_1}\right]\tilde{R}, \tag{73}$$

$$\tilde{l}_2 = -\varepsilon_2\left[1 - \Sigma_2\frac{\rho_1\epsilon}{\Delta}\right]\tilde{t} - \varepsilon_2\Sigma_2\left[1 + \frac{\rho_1\delta}{\Delta}\right]\tilde{R}, \tag{74}$$

where

$$\Delta \equiv \frac{\gamma + (1-\gamma)\frac{\rho_1}{\rho_2}}{(1-t)} + (1-\pi_1)\omega\Sigma_1\varepsilon_1\rho_1 + (1-\pi_2)(1-\omega)\Sigma_2\varepsilon_2\rho_1 > 0, \tag{75}$$

$$\epsilon \equiv (1-\pi_1)\omega\varepsilon_1 + (1-\pi_2)(1-\omega)\varepsilon_2 > 0, \tag{76}$$

$$\delta \equiv -\frac{(1-\gamma)/\rho_2}{(1-t)} + (1-\pi_1)\omega\varepsilon_1(1-\Sigma_1) - (1-\pi_2)(1-\omega)\varepsilon_2\Sigma_2. \tag{77}$$

ϵ is a measure for the weighted labor supply elasticity where the certainty equivalent of each period's income is used as a weight.

We can sign the following elasticities. First, the consumption elasticities with respect to the tax rate are unambiguously signed: $\varepsilon_{c_1t} < 0$, $\varepsilon_{c_2t} < 0$. Next, the elasticity of second period consumption with respect to the interest factor is unambiguous as well, $\varepsilon_{c_2R} > 0$, because $1 + \frac{\rho_1}{\Delta}\frac{\delta}{\Delta} = \frac{1}{\Delta}\left[\frac{\gamma}{1-t} + (1-\pi_1)\omega\varepsilon_1\rho_1\right] > 0$. Second, as long as we assume $\delta < 0$, the first-period consumption elasticity with respect to the interest factor will be negative, $\varepsilon_{c_1R} < 0$ and standard saving behavior is obtained. This assumption holds true if either there is no first-period income, if $\pi_1' - \pi_1$ is sufficiently small, or if the tax labor tax rate t is sufficiently high. For $\delta < 0$, a higher net interest factor makes first-period consumption less attractive and second-period consumption more attractive. These signs of the elasticities would also be found in the absence of risk.

Third, the elasticity of second-period labor supply with respect to the interest factor is unambiguously negative, i.e., $\varepsilon_{l_2R} < 0$, since $1 + \frac{\rho_1\delta}{\Delta} = \frac{1}{\Delta}\left(\frac{\gamma}{(1-t)} + (1-\pi_1)\omega\varepsilon_1\rho_1\right) > 0$. Moreover, if δ is negative, then $0 < 1 + \frac{\rho_1\delta}{\Delta} < 1$. Consequently, the first-period labor supply elasticity with respect to the interest factor is negative, if $\Sigma_1 < 1$, since $1 + \frac{\rho_1\delta}{\Delta} - \frac{1}{\Sigma_1} < 0$ in that case. The latter assumption is equivalent to assuming $\pi_1' > \pi_1$. This is a relatively weak requirement. For the special case of multivariate normally distributed skill shocks, it can be shown that this assumption is equivalent to require (global) absolute prudence being larger than (global) absolute risk aversion. The latter holds for most utility functions and should also carry over under uncertainty under mild conditions.

Fourth, we assume that the substitution effect is dominant to obtain standard labor supply behavior, i.e. $\varepsilon_{l_i t} < 0$. Thus, we impose $1 - \Sigma_i \frac{\rho_1 \epsilon}{\Delta} > 0$. These assumptions imply $-\frac{1}{(1-\pi_2)(1-\omega)\varepsilon_2} < \frac{(\Sigma_2-\Sigma_1)(1-t)}{\gamma\frac{1}{\rho_1}+(1-\gamma)\frac{1}{\rho_2}} < \frac{1}{(1-\pi_1)\omega\varepsilon_1}$. Therefore, a sufficient condition to ensure standard behavior of labor supply is that the difference between Σ_1 and Σ_2 is not too large (or that they are close to being equal) such that $\Sigma_1 \approx \Sigma_2$ holds.

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